BUILDING STONES AND CLAYS

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A HANDBOOK FOR ARCHITECTS AND ENGINEERS

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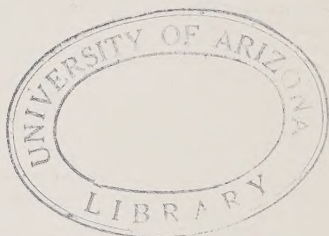———

With 303 Copper Halftones and 10 Zinc Etchings

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TO MY FATHER AND MOTHER
NOW IN THE EIGHTY-FIFTH YEAR
OF THEIR AGE, INTERESTED IN
SCIENCE, LITERATURE AND PHILOSOPHY,
THIS BOOK IS AFFECTIONATELY

Dedicated

PREFACE

The present volume is an outgrowth of the author's needs in his own classroom. The matter is essentially that presented to his classes in a brief course in the College of Applied Science for Civil Engineers, in the College of Fine Arts for Architects and in the College of Liberal Arts for students of Economic Geology. The work has been multigraphed, bound and used as a manuscript textbook. It is now published for the greater advantage to his own students, and with the hope that it may be useful to others.

The object has been to furnish an elementary knowledge of the essential minerals in building stones and the objectionable minerals they sometimes contain; to show the chief characteristics of the more important building stones; to give their geographical distribution and range in compressive strength; to impart some information as to the physical and chemical properties of clays and the products that may be manufactured from them.

The author has attempted to state the essential facts and explanations as clearly and simply as possible and to observe a logical order and a due proportion between different parts. The larger amount of space is given to each type of building stone in the state where it is the most abundant.

Great care has been taken in classifying and arranging the subject matter that it may follow the order as closely as possible of the various lecture courses on building stones and clays in our different colleges and universities.

The author wishes to express here his great indebtedness for constant assistance in the preparation of this work to his colleagues on the University Faculty: Professors T. C. Hopkins, Burnett Smith, A. E. Brainerd, B. W. Clark and H. G. Turner. Also his greater indebtedness to Prof. G. H. Chadwick of the University of Rochester for his careful checking of results and verifying data, and to Prof. W. F. Prouty of the University of Alabama for his contribution on the Marbles of Alabama.

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<div align="right">Charles Henry Richardson.</div>

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BUILDING STONES AND CLAYS

CHAPTER I

INTRODUCTION

The term building stones as here used embraces all those forms of igneous, sedimentary and metamorphic rocks that are utilized for structural or decorative purposes, whether that use be large as in the case of granites, or small like the ophicalcites.

The igneous rocks are treated first, even though they are more difficult for the beginner to understand, because they are the ultimate source of the sedimentaries and their metamorphic derivatives. This arrangement, however, does not preclude the study of the sedimentaries first, if one so chooses.

In this discussion an attempt has been made to give the reader some of the more salient geological and mineralogical features, both natural and artificial, to enable the architect and engineer by simple tests to determine what objectionable constituents, if any, are present and thereby select wisely material that will last well and be harmonious in its environment.

The author realizes that it is not from books alone that Geology and Mineralogy are learned. It requires a large and varied suite of dressed, unpolished and polished specimens, together with a careful study of their structural relations in the field, to enable one to choose only the best material. It is furthermore essential to see the stone quarried, dressed and seasoned.

MINERALS OF BUILDING STONES

Definition.—A mineral is generally defined as a natural inorganic element, or compound, with fairly definite chemical composition. A rock is a mineral aggregate. This aggregation must be an essential portion of the crust of the earth. To be a geological formation it must represent a mappable area. The igneous rocks may occur either as eruptives that have flowed out over the surface of older formations, or as irruptives in stocks, sheets, dikes, etc., that appear at the surface only through continental denudation. The sedimentary

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rocks occur in stratified beds. In some instances the planes of stratification are lost.

Number.—The number of minerals necessary in the formation of a given type of building stone is exceedingly small. Calcite is the only mineral necessary in statuary marble. Analyzed samples of this marble from western Vermont have given 99.5 per cent calcite and .5 per cent silica. A sandstone may consist of little more than grains of quartz held together by the pressure to which they have been subjected. A true syenite requires but two minerals, orthoclase and hornblende. A granite demands the presence of quartz and orthoclase; and usually some ferromagnesian mineral is present, as biotite or hornblende.

A microscopic examination of building stones usually adds a few minor minerals to the requisite number for a given type of rock. These are of importance in the weathering of a stone but not necessary in its commercial definition.

Classification.—The minerals of building stones are classified as essential and accessory, or as original and secondary. The essential minerals determine the definition of a given type of rock. Quartz is essential in a sandstone, quartz and orthoclase in a granite. An accessory mineral is one that is usually present but of minor importance. Its presence may be recognized microscopically or macroscopically. For example, apatite or magnetite may occur in a granite.

An original mineral as applied to the necessary constituents of building stones is one that was present when solidification first occurred. It is always an essential mineral, but original minerals are not always essential. Apatite and zircon when present in granites are amongst the first minerals to solidify from an acid magma yet they are not essential to the commercial definition of a granite. A secondary mineral is one that is derived from some other mineral or minerals either by the chemical action of percolating waters or by molecular rearrangement. Olivine is an essential mineral in peridotite while serpentine results from the loss of the iron and the hydration of the magnesium in olivine.

In order to best understand the nature of structural stones some knowledge of mineralogy is necessary. Even a descriptive elementary method of treating minerals has some value. It would not seem advisable to enter into detail to any considerable extent for most minerals may be recognized by a few simple tests. These will enable an architect or engineer to arrive easily at his definition of a given type of structural stone.

Essential.—The number of minerals occurring as essential constituents in building stones is exceedingly small. The list

may be summed up in the various varieties of quartz; four families, the feldspars, micas, amphiboles, pyroxenes; three anhydrous silicates, olivine, epidote, nephelite, or the variety eleolite; three hydrous silicates, talc, serpentine, chlorite; three carbonates, calcite, aragonite, dolomite; and one sulphate, gypsum.

Non-essential.—The non-essential minerals are vastly greater in number but they occur in small proportions and often of microscopic size. The presence of some of these is exceedingly deleterious while others are harmless. These may be summed up in two elements, four sulphides, two carbonates, seven oxides, one phosphate, one chloride, one fluoride, together with several anhydrous and hydrous silicates. A brief statement concerning the more important of these minerals will suffice.

DESCRIPTION OF MINERALS

Quartz.—Quartz is an oxide of silicon, SiO_2. It is 7 in the scale of hardness, 2.65 in specific gravity, vitreous in luster, insoluble in the common mineral acids. It can easily be recognized by its insolubility, its luster and superior hardness to all other essential minerals in building stones. It is one of the most widely distributed of all minerals. It composes most of the sands of the sea shore and river plains. It is essential in all sandstones and mica schists. It is present in all granites, gneisses, quartzites, liparites, etc. The quartz grains in fragmental sandstones have sometimes undergone a secondary growth by a deposition of crystallized silica with like orientation to the original nucleus.

Quartz is furthermore one of the most indestructible of minerals for there is no higher oxide of silicon. The fluid cavities sometimes found in quartz cause the rock mass rich in silica to scale after being subjected to the heat of a burning building.

The Feldspars.—The term feldspar is a family name embracing a group of minerals with many characteristics in common. They are silicates of aluminum with either potassium, sodium, or calcium present, while magnesium and iron are always absent. There are many intermediate species between the sodium and calcium members which are connected with each other by insensible gradations. Some of the common characteristics of the family are as follows: (1) Crystallization in the monoclinic or triclinic systems with a close resemblance among the different species in general habit, cleavage angle and method of twinning. (2) Colors shading from white to green or red. (3) Hardness falling between 6 and 6.5. (4) Specific gravity generally between 2.5 and 2.75.

Orthoclase, K_2O, Al_2O_3, $6SiO_3$, is an acid feldspar occurring as an essential constituent in all granites, most gneisses and true syenites. It is easily recognized by a possible cleavage angle of 90 degrees and the absence of striations on all cleavage planes. It fuses at 5 and is insoluble in mineral acids.

Microcline crystallizes in the triclinic system. Its chemical composition is the same as that of orthoclase, K_2O, Al_2O_3, $6SiO_2$. It often shows a peculiar shade of green which aids in distinguishing the crystals from those of the other feldspars. In case of the building stones it often requires a microscopic examination to establish the difference. Its home is with the acid irruptives.

Plagioclase is the term often given to designate the remaining members of the feldspar family all of which are triclinic in system of crystallization. They are albite, oligoclase, andesine, labradorite and anorthite.

Albite, as the name implies, is usually white in color. Its formula is Na_2O, Al_2O_3, $6SiO_2$. It fuses at 4 and is insoluble in mineral acids. It occurs in many granites along with orthoclase and is usually distinguishable by its greater whiteness. In some highly colored granites the few white crystals present are albite. When it occurs as the essential feldspar with hornblende it constitutes a diorite.

Oligoclase is intermediate in composition between albite and anorthite. It fuses at 3.5 to an enamel-like glass and is imperfectly acted upon by mineral acids. It is often recognized by fine striations or parallel lines on some cleavage plane. Its home is with both the irruptives and the eruptives.

Andesine is also intermediate between albite and anorthite. It fuses in thin splinters before the blowpipe and is imperfectly soluble in mineral acids. Its color is usually white or gray. It gives definition to the rock called andesite. It occurs in some syenites and porphyries.

Labradorite is more basic than the preceding feldspar. It fuses at 3 to a colorless glass and is partially soluble in HCl. It shades in color from gray to green and often presents a beautiful iridescence, especially when polished, in which blue and green are predominant colors but yellow and fire-red colors also occur. It is often finely striated upon the cleavage planes. It occurs with hypersthene in the building stone known as norite. Its home is also with the gabbros, diabases and dolerites.

Anorthite is the most basic member of the feldspar family. Its formula is CaO, Al_2O_3, $2SiO_2$. It fuses at 5 to a colorless

glass and is soluble in HCl with a separation of gelatinous silica. In color it shades from white to red. Its home is with the basic intrusives. Some of the New England diabases bearing anorthite constitute the finest road metal.

It is important before selecting any granite for a massive structure to examine carefully microscopic slides of the stone. If the feldspar has already suffered kaolinization the rock should be rejected. The microscope often reveals cavities and flaws so filled with impurities and products of decomposition as to render the feldspar quite opaque. Such a building stone will not long withstand the destructive effects of weathering agencies.

The color often imparted to granites, gneisses and quartz porphyries is due to the color of the prevailing feldspar. In the red granites the pigment in the feldspar is ferric iron. In the green granites it has been attributed to ferrous iron and in the delicately pink granites to manganese.

The Micas.—The mica family includes a series of closely related minerals characterized by a highly perfect basal cleavage. They are easily separable into plates varying in thickness from one thousandth to one fifteen hundredth of an inch in thickness. They all fall in the monoclinic system.

Muscovite, chemically considered, is an orthosilicate of aluminum, potassium and hydrogen. It is known also as the potassium mica or the white mica. In some light colored granites it is practically the only mica present. This holds especially true of the white granite of Bethel, Vermont. The thin laminae of muscovite are flexible and spring back with considerable force into normal position when bent. Its hardness is 2.3. Its gravity is 2.9. Muscovite is insoluble in the mineral acids, and when it bears no iron it possesses greater powers of endurance than the other members of the mica family.

Biotite is also an orthosilicate of aluminum, potassium, hydrogen, magnesium and iron. It is known as the iron mica and the black mica. The presence of iron favors decomposition for when the mineral is once coated with a thin film of the oxide of iron it is rapidly disintegrated. Biotite is 2.8 in hardness and sometimes reaches a specific gravity of 3. The presence of large quantities of biotite in a granite increases the weight per cubic foot, and decreases the life of the stone. The finely pulverized mineral is decomposed by sulphuric acid with a separation of the silica in minute scales.

Phlogopite is closely related to biotite in composition but

carries less iron. It is known as the magnesium mica, or amber mica, on account of its amber-like reflections. It often exhibits asterism in transmitted light. Its hardness is 2.7 and its specific gravity 2.8. It is completely decomposed by sulphuric acid with a separation of the silica in minute scales. The home of phlogopite is with the marbles and serpentines in which it often becomes an objectionable constituent.

Lepidomelane is in part an orthosilicate and in part a more basic compound. It is chiefly characterized by a large amount of ferric iron. It is best regarded as a variety of biotite.

The presence of the various micas in limestones, dolomites and marbles may be regarded as objectionable for they are

Fig. 1.—Boulder of orbicular granite, Orleans County, Vermont. Photo. by C. H. Richardson.

difficult to polish and scale off easily leaving the stone pitted. In such rocks the micas are of secondary origin. In the granites and gneisses the micas are of primary origin. They should be uniformly scattered throughout the stone in fine scales for with their perfect cleavage they themselves constitute an element of weakness. When in spherical aggregations as in the granite of Craftsbury, Vermont, they give rise to the orbicular granites. (See Fig. 1.)

The Amphiboles.—The amphibole family includes a group

of minerals that crystallize in the orthorhombic, monoclinic and triclinic systems. Those occurring in building stones fall in the monoclinic system and the representatives are tremolite, actinolite and hornblende.

Tremolite is a silicate of calcium and magnesium. Hardness of 5.5 and specific gravity of 3. It sometimes appears as short, stout prisms, and sometimes columnar, or fibrous. It is an objectionable constituent as a secondary mineral in marbles, for the stone becomes pitted through the loss of lime and the falling out of the minute crystals of tremolite. Furthermore, the mineral often changes color from a pure white when quarried to a dirty gray upon exposure to the atmosphere.

Actinolite is closely related to tremolite in composition but has a little of the magnesium replaced by iron which imparts a bright green or grayish color to the mineral. Hardness of 5.5 and gravity of 3.1. The crystals are short, bladed, columnar and fibrous. Its home is with the metamorphics.

Hornblende is an aluminous variety of amphibole. Hardness 5.5 to 6. Specific gravity 3.2. Its color is often greenish black to black. It is an essential constituent in certain granites like the granite of Quincy, Mass., gneisses, schists and diorites. The crystals are often long and prismatic. The mineral may easily be identified by its black color and cleavage angles of 56 and 124 degrees. The cleavage is far more pronounced than it is in the pyroxenes.

The Pyroxenes.—The pyroxene family embraces a number of species that fall in the orthorhombic, monoclinic and triclinic systems of crystallization. The metasilicates of calcium, magnesium and iron are the most prominent members of the groups. They all present a fundamental prismatic form with an angle of 87 or 93 degrees parallel with which there is a pronounced prismatic cleavage.

Enstatite is a metasilicate of magnesium, MgO, SiO_2. Its hardness is 5.5 and specific gravity 3.2. In color it is often gray but when iron displaces a part of the magnesium the mineral is bronze-like in color. Its home is in the peridotites and the serpentines derived from them. In its hydration talc is the metamorphic product.

Hypersthene, $(Fe,Mg)O$, SiO_2. Hardness 5.5. Specific gravity 3.4. In color the mineral shades from a dark brownish green to a greenish black. Hypersthene is an essential constituent of certain so-called granites like the Keeseville, N. Y., norite. It is also found in some gabbros and andesites. It

sometimes produces black knots in the norites. These represent a basic segregation in the cooling of the magma from which norite is derived. The presence of much hypersthene is undesirable, for the mineral, on account of its iron content, is easily decomposed on exposure to the corrosive agents of the atmosphere.

Augite is for the most part a normal metasilicate of calcium, magnesium and iron. Hardness 5.5. Specific gravity 3.4. Its color is usually green or greenish black and the crystals are short, thick and prismatic. Its cleavage angles of approximately 87 and 93 degrees, together with its grayish green color, readily distinguish it from hornblende. It occurs sparingly in some building stones like the nordmarkite of Mount Ascutney, Vermont. It is an essential constituent with the triclinic feldspars in diabase and basalt. By a conversion of the augite into hornblende the latter rocks pass into the diorites.

The Nephelite Group.—The only member of the nepheline group of minerals occurring as an essential constituent in building stones is nephelite. It is an orthosilicate of aluminum, sodium and potassium. Its hardness is 5.8. Its specific gravity is 2.65. Its home is with the intermediate and basic rocks rather than with the acidic. The syenites bearing the variety of nephelite known as eleolite often present a greasy appearance suggestive of an oiled surface. Free quartz is absent, for if an excess of silica sufficient to form quartz had been present in the magma then the acid feldspars would have been formed instead of nephelite. Its presence in a building stone is easily established by pulverizing a few grams of the rock and digesting it with concentrated HCl or dilute HNO_3 when, in the presence of nephelite, the silica of this mineral will separate out as a gelatinous product of decomposition.

The Chrysolite Group.—The one important member of this group is the orthosilicate of magnesium and iron, olivine, in which the ratio of the magnesium to the iron varies widely. Some analyzed samples have shown this ratio as 16 : 1, others as 2 : 1. Its hardness is 6.7. Its specific gravity is 3.3. The mineral is named from its olive green color. Its home is with the basic and ultra-basic rocks. In its metamorphism it passes into serpentine which sometimes becomes a highly decorative structural stone yet better suited for interior decorative work.

The Epidote Group.—The one important member of this

group of minerals is epidote itself. Its hardness is 6.8. Its specific gravity is 3.3. It is an orthosilicate of calcium, aluminum and iron with a little water of crystallization. It is of a peculiar pistachio green color seldom represented by other minerals. It is sometimes found sparingly in granites as at Enfield, N. H., and is a common constituent of many gneisses, schists and serpentines.

The Hydrous Silicates.—The three hydrous silicates of considerable significance in structural and decorative stones are chlorite, serpentine and talc.

Chlorite.—The term chlorite embraces a considerable number of minerals closely related to the micas but differing from them in brittleness and in a larger percentage of water. Chemically considered the chlorites are silicates of aluminum, iron and magnesium, with chemically combined water. They are characterized by their green color, perfect cleavage and inelastic foliae. Their hardness varies but approximates to 2.5 and their specific gravity falls between 2.5 and 2.9. Chlorites are secondary minerals derived from the alteration of amphiboles, pyroxenes and micas.

The mineral imparts a green color to the chlorite schists which often consist of scales of chlorite and grains of sand. Chlorite is the ferromagnesian mineral in certain gneissoid granites like that of Lebanon, N. H., which was first classified as a protogene gneiss. The chlorite is here derived from the metamorphism of biotite.

Serpentine is a hydrous silicate of magnesium, $3MgO,2SiO_2,$ $2H_2O$. Hardness varying from 2 to 4. Its specific gravity is 2.65. It occurs in varying shades of green, sometimes greenish black. It crystallizes in the monoclinic system but it is the massive form that finds use as a decorative stone. When it occurs with calcite, magnesite and dolomite it constitutes the verd antique marbles. It sometimes occurs as minute green patches scattered through other marbles where its presence is objectionable. It occurs also as a metamorphic product resulting from the alteration of the magnesium silicates in diabase, basalt and peridotite. Massive serpentine is easily recognized by its inferior hardness to marble, its green color, its absence of cleavage planes and the large percentage of water derived upon ignition. (See Fig. 2.)

Talc is an acid metasilicate, $3MgO, 4SiO_2, H_2O$. Its hardness varies from 1 to 2.5. Its specific gravity is 2.75. Its color shades from white to green. When it occurs in the massive form it constitutes the useful stone known as steatite,

which finds application in laboratory tables, sinks, stationary washtubs, stoves, etc. The mineral is easily recognized by its soapy feel and the ease with which it can be abraded with the thumb nail.

The Carbonates.—Calcite, aragonite and dolomite are the three carbonates that occur as essential minerals in building stones. They are easily distinguished from the preceding minerals by their effervescence in HCl. They are secondary in origin resulting largely from the alteration of other minerals, together with the solution and fine comminution of the testa of mollusks and crustaceans.
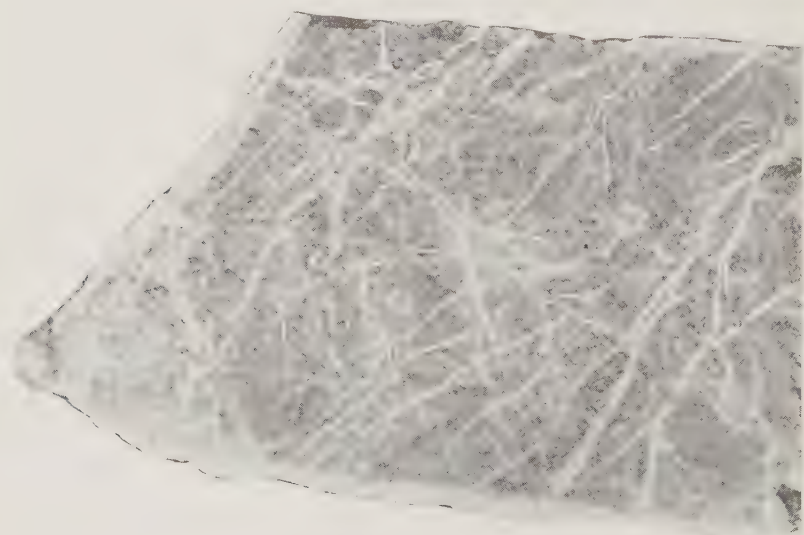
Fig. 2.—Block of verd antique marble, Roxbury, Vermont. Photo. by C. H. Richardson.

Calcite occurs filling the minute cavities in the rocks of all classes and of all ages. Formula, $CaCO_3$. Its specific gravity is 2.71. Pure statuary marble contains little else than calcium carbonate. It furnishes the essential constituent in most marbles, and is one of the two requisite constituents of dolomites. Calcite is easily recognized by its definite hardness of 3, by its facile cleavage and consequent brittleness and by its rapid effervescence with cold dilute HCl.

Aragonite has the same formula as calcite but instead of crystallizing in rhombohedrons of varied habit like calcite it falls in the orthorhombic system in prismatic forms. Its

hardness is 3.7 and its specific gravity 2.95. Some decorative marbles like the onyx of San Luis Obispo, California, are nearly pure aragonite. The mineral is distinguished from all others save calcite by rapid effervescence in cold dilute HCl, and from calcite by falling to pieces before the blowpipe and by turning a beautiful pink when the fine powder is boiled with the nitrate of cobalt.

Dolomite is a double carbonate of calcium and magnesium, $CaCO_3$, $MgCO_3$. Its hardness is 3.7 and its specific gravity 2.85. It crystallizes in the hexagonal system in rhombohedrons with curved faces, often with a pearly luster. It effervesces slowly, if at all, in cold dilute HCl but rapidly in warm HCl. Many of the white marbles like that of Stockbridge, Mass., and the mottled marbles like those of Swanton, Vermont, are dolomites. (See Figs. 3 and 4.)
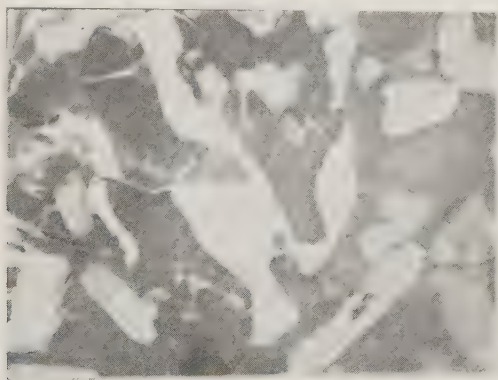
Fig. 3. — Polished sample of jasper marble, Swanton, Vermont. Photo. by C. H. Richardson.

Gypsum, $CaSO_4$, $2H_2O$, is the only sulphate that occurs as an essential constituent of any building stone. Its hardness is 2 and its specific gravity 2.3. In color it is usually white but sometimes grayish. It crystallizes in the monoclinic system with forms simple in habit. The mineral seldom occurs in the crystalline rocks but it forms extensive beds amongst the stratified limestones and clays where it becomes a rock mass of large commercial significance. Alabaster is a fine translucent variety that is used for ornamental purposes. In the absence of the water of crystallization the mineral passes into anhydrite which has been substituted sometimes for white marble. This use is objectionable for

anhydrite absorbs water upon exposure and expands thereby throwing buildings out of plumb.

The Non-essential Minerals.—The number of non-essential minerals sometimes occurring in building stones approximates forty. In many cases these are microscopic constituents. In others they are visible to the eye and easily recognized. The lack of space will permit an outline of only a few and these will be the ones most objectionable when present in any building stone.

Pyrite, FeS_2, is a disulphide of iron. Its hardness is 6.3. Its specific gravity is 5. In color it is a pale brass yellow. It occurs in building stones in the form of cubes of the iso-
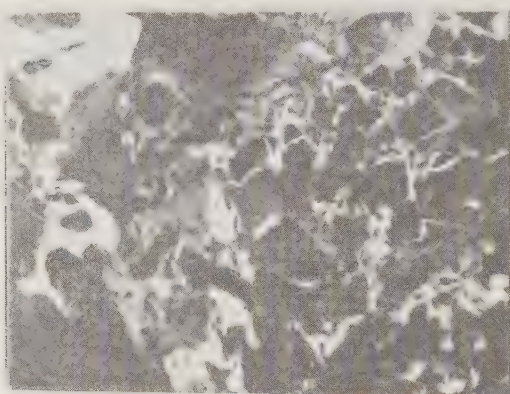
Fig. 4.—Polished sample of lyonaise marble, Swanton, Vermont. Photo. by C. H. Richardson.

metric system and in a microscopic, granular and amorphous condition. In this latter form its oxidation is far more active than when in cubes. In its decomposition either soluble sulphates or free sulphuric acid is formed and the stone soon presents a dingy and unkempt appearance. In the calcareous rocks bearing magnesium the presence of pyrite becomes exceedingly objectionable. The free sulphuric acid formed in the decomposition of the pyrite unites with magnesium and forms a soluble efflorescent salt that creeps to the surface and is replaced from time to time by the less soluble, yet

objectionable, calcium sulphate. According to James Hall efflorescence is frequently observed on buildings constructed of the bluestone of the Hudson River group. In case the mortar with which the structural blocks are laid contains magnesium efflorescent patches may be observed creeping mainly from the joint planes and bedding planes of the finished structure. Such an exhibition may be seen on St. Peter's Church, State Street, Albany, N. Y.

Marcasite has the same chemical formula as pyrite, FeS_2. Its hardness is 6.3 and its gravity is 4.9. It crystallizes in prismatic forms in the orthorhombic system and is paler in color than pyrite. A. Julien has pointed out the greater tendency of marcasite to undergo atmospheric alterations and shown its profound influence upon the durability of building stones. Where the two forms of iron disulphide occur together, either through crystallization or alteration, as the proportion of marcasite increases the specific gravity of the rock mass decreases, the color becomes paler, and the danger of objectionable weakening and discoloration is increased.

Owing to the tendency of all sulphides to decompose upon exposure to the atmosphere structural stones showing their presence should be rejected. Sulphur to the amount of .2 per cent may be readily detected by fusing the rock in powdered form with sodium carbonate on charcoal with the blowpipe, transferring the fused mass to a silver coin, moistening with water, when in the presence of sulphur, a dark stain due to the formation of silver sulphide will appear on the coin.

Siderite is a carbonate of iron, $FeCO_3$. Its hardness is 3.7 and its specific gravity 3.8. Its color is usually gray but it turns brown upon exposure to the atmosphere. The mineral crystallizes in curved rhombohedrons of the hexagonal system and occurs as scattered crystals or in groups in many clays and limestones. Any limestone, dolomite or marble, bearing even microlites of siderite will soon present a dull or dead surface. 0.1 of 1 per cent of this mineral can be detected by the borax bead which in its presence becomes bottle green in the reducing flame.

Ankerite, $2CaCO_3$, $MgCO_3$, $FeCO_3$, is a triple carbonate. Its hardness is 3.7 and its specific gravity 3. It crystallizes in the same forms as siderite. Its occurrence in building stones is less frequent than that of siderite but when present it is always objectionable.

Hematite, Fe_2O_3, is an oxide of iron. Its hardness is 6

and its gravity 5. Its color shades from red to black but its streak is cherry red or blood red. It occurs in the rocks of all ages. The specular variety is mostly confined to the crystalline or metamorphic rocks. In granites it is usually confined to minute scales of bright red color. In an amorphous form it furnishes the cement in the red or brownish sandstones. Its occurrence as a cement is not as frequent as that of the hydrated oxides of iron, turgite and limonite. These are present in the Triassic sandstones of Longmeadow, Mass.

Magnetite, Fe_3O_4, is distinguished from the other oxides of iron by its black color and strong magnetism. Its hardness is 6 and its specific gravity is 5.1. It crystallizes in regular octahedrons of the isometric system. Its home as an original constituent is in many granites and metamorphic sedimentaries. It is almost invariably present in the basic igneous rocks. Whenever magnetite is present in an appreciable quantity in any rock it ultimately becomes converted into the hydrated oxide of iron which stains the stone a rusty red color.

Garnet, $3RO$, R_2O_3, $3SiO_2$. R stands for the bivalent metals like calcium and magnesium, R_2 represents the trivalent metals like aluminum and ferric iron. The hardness of garnet is 7. Its specific gravity is 3.3. In color the mineral shades from white to red. It crystallizes in the isometric system in regular dodecahedrons and leucitohedrons. Its home is with the granites, gneisses, schists, limestones, and sometimes serpentines. Occasionally it appears in the basic irruptives. Its presence in any type of building stone is objectionable. On account of its brittleness it breaks away from its matrix in the dressing of a stone and renders a perfect polish far more difficult to obtain. Iron garnets break down due to the oxidation of the iron on long exposure to the atmosphere and the stone becomes stained with the characteristic iron rust.

CHAPTER II

PHYSICAL PROPERTIES AND WEATHERING OF BUILDING STONES

Physical Properties.—There are several physical properties that materially affect the value of building stones. Sometimes these properties have greater significance than the minerals themselves.

Color.—The color of a stone is often a guide to its suitability for a definite purpose. A dark and somber sandstone would appear inharmonious in a residential section in a large city where all neighboring buildings were constructed of a creamy white sandstone, or a white marble. Many an architect has builded well because he selected only those colors that were harmonious in their environment. The color of building stones is widely varied and the opportunity of choice correspondingly large. The color may be due to one or more of several causes. Pink tinted feldspars give rise to a pink granite like that of Westerly, R. I. Red orthoclase renders the prevailing color of the resulting granite red, like that of Peterhead, Scotland. Sometimes it is due to a commingling of the feldspars with small crystals or even scales of biotite as in the light and dark granites of Barre, Vermont. If the feldspars are clear and glassy they absorb light, and if they are white and opaque they reflect light. (See Figs. 5 and 6.)

The chief coloring matter in red sandstone is the ferric oxide, Fe_2O_3. This may appear as a pigment in the individual sand grains that comprise the essential mineral of the rock mass, or it may appear as the cement that binds the sand grains together. The hydrated oxides of iron serving as cements afford colors shading from a reddish brown to a yellow hue. Clay as a cement in sandstones produces a drab or blue coloration. A gray color may also be produced by the presence of the carbonates and sulphides of iron. The pigment in the black marbles of Glens Falls, N. Y., is uncombined carbon. (See Figs. 7 and 8.)

The color of building stones in many cases is not permanent. The nordmarkite of Mount Ascutney, Vermont, turns green

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upon exposure to the atmosphere. Sandstones and limestones containing carbonaceous matter often bleach. The red and green slates may fade. If the minerals responsible for these

Fig. 5.—Polished disc of medium gray granite, Boutwell, Milne and Varnum quarry, Barre, Vermont. Photo. by C. H. Richardson.

Fig. 6.—Polished slab of white granite, Bethel, Vermont. Photo. by C. H. Richardson.

changes in color are not uniformly distributed throughout the stone the structure becomes blotched and unsightly. (See Fig. 9.)

Hardness.—The hardness of a mineral is its resistance to abrasion. The resistance to abrasion in a building stone
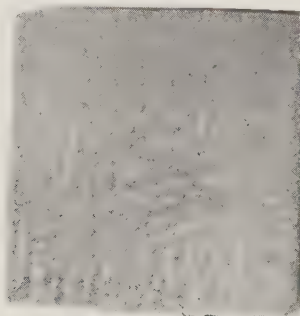
Fig. 7.—Small block of red Medina sandstone, Medina, New York. Photo. by C. H. Richardson.

Fig. 8.—Rock faced sample of Warsaw bluestone, Warsaw, New York. Photo. by C. H. Richardson.

depends upon the hardness of the individual grains themselves and upon their state of aggregation. A sandstone whose individual grains are 7 in the scale of hardness may wear away rapidly from the solution of the cement that binds the

sand grains together. Such stones are not well suited for risers, treads and thresholds.

Specific Gravity.—The weight of a cubic foot of building stone becomes an important factor where haulage by teams demands a certain price per hundred weight rather than per cubic foot. This weight may be ascertained by multiplying the specific gravity of the stone by 62.5, the weight of a cubic foot of water. However, the more dense a stone is the heavier it will be.

Fig. 9.—Slab of red slate from Granville, New York, showing a white vein-like band formed by the leaching out of the pigment in the slate. Photo. by C. H. Richardson.

Density.—The density of a stone is its degree of compactness. The more dense a building stone is the less water it will absorb, and consequently it possesses less danger of injury from freezing when the quarry water is present in the

blocks. Such building stones also possess greater compressive and tensile strength.
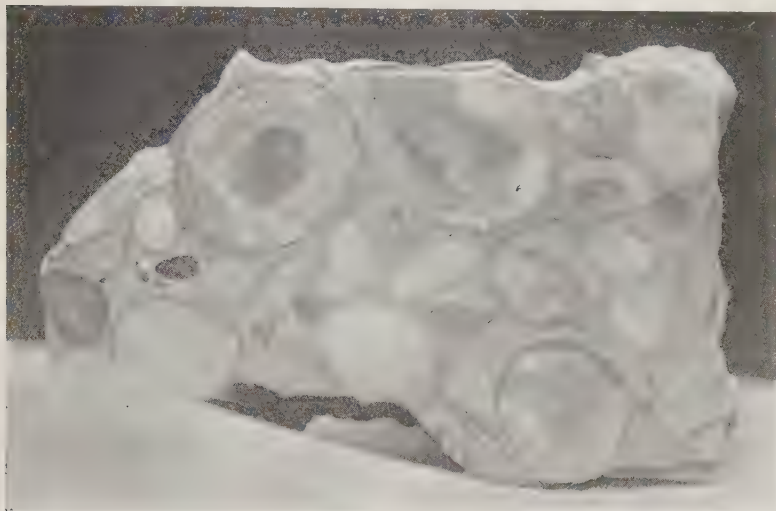
Fig. 10.—Agate conglomerate, Brazil. Photo. by C. H. Richardson.

Fig. 11.—Lambertville trap rock (diabase), Lambertville, New Jersey. By courtesy of J. Volney Lewis.

Texture.—The texture of building stones is widely varied. It ranges from a coarsely porphyritic texture in the pegmatites, and the large, rounded, or angular fragments in the
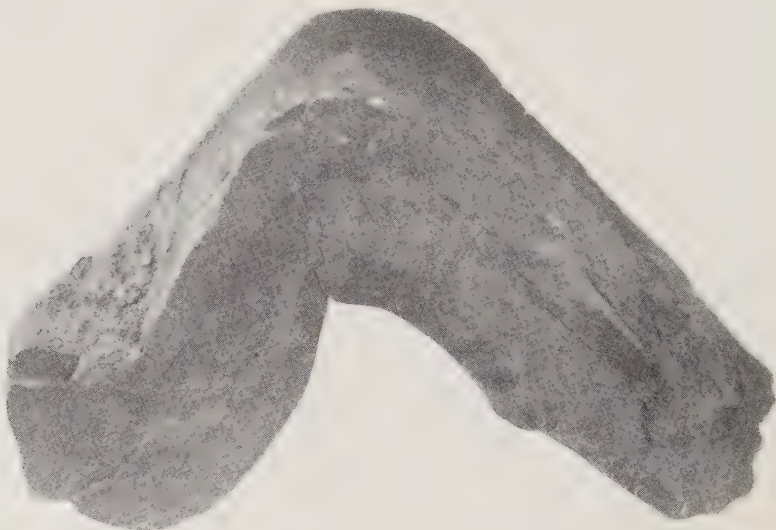
Fig. 12.—Anticline in memphremagog slate belt, Albany, Vermont. Photo. by C. H. Richardson.
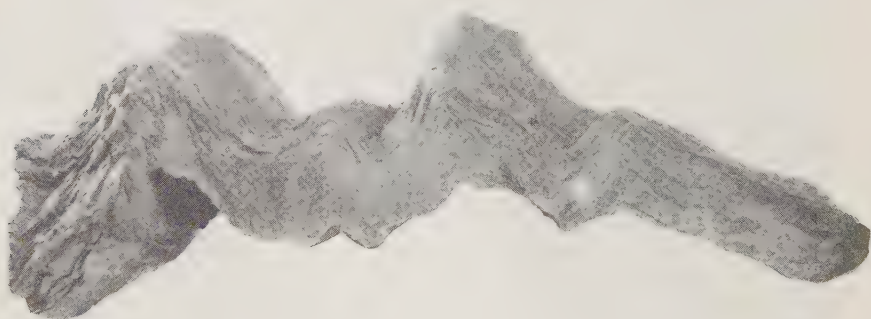
Fig. 13. — Small anticlinorium from Memphremagog slate belt, Woodbury, Vermont.   Photo. by C. H. Richardson.

conglomerates, to a fine microscopic assemblage of minerals as in the basalts, or the slates derived from the ashes of extinct volcanoes.   The texture is macroscopic when the individual minerals can be easily ascertained by the naked eye and microscopic when the aid of a petrographic microscope is

demanded for the definition of a structural or decorative stone. (See Figs. 10 and 11.)

State of Aggregation.—The hardness, or softness, of a rock depends quite largely upon this factor. It influences also the working qualities of a stone. If the grains adhere loosely like the itacolumite of North Carolina, the stone is friable. If a stone is exceedingly fine grained and compact it is called flinty.

Fig. 14.—E. R. Fletcher granite quarry, Woodbury, Vermont, showing dome-like sheeted structure. Photo. by C. H. Richardson.

Chemical Properties.—Many building stones have been analyzed quantitively and their percentage composition calculated. From such analyses a building stone like granite which is rich in its silica content is called acidic. A syenite, bearing no free quartz, consisting of orthoclase and some

ferromagnesian mineral, intermediate. Rocks possessing no free silica or orthoclase and therefore low in their silica content are classified as basic. Rocks consisting principally of calcium carbonate, or calcium and magnesium carbonates, are calcareous. Those rich in clay are argillaceous. When rich in carbon they are carbonaceous. When iron is abundant they are called ferruginous, and when they enclose bitumen they are bituminous.

Structures that Aid in Quarrying.—The structure in sedimentary rocks is anticlinal when an arch-like fold inclines in opposite directions from an axis. (See Figs. 12 and 13.)

The corresponding arrangement of the sheets in a sheeted granite quarry suggests a dome. (See Fig. 14.)

The structure of sedimentary rocks is synclinal when they form a trough-like fold or bend in the same direction. (See Fig. 15.)
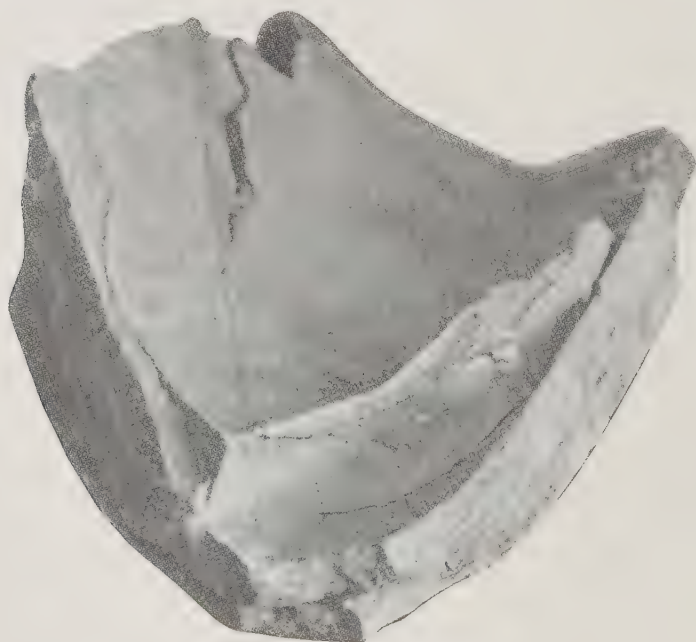
Fig. 15.—Syncline in sericite schist, Wolcott, Vermont. Photo. by C. H. Richardson.

Joint planes are common features in the rock of all classes and of all ages. In the granites they represent structure planes that result from the cooling of a molten mass, and are
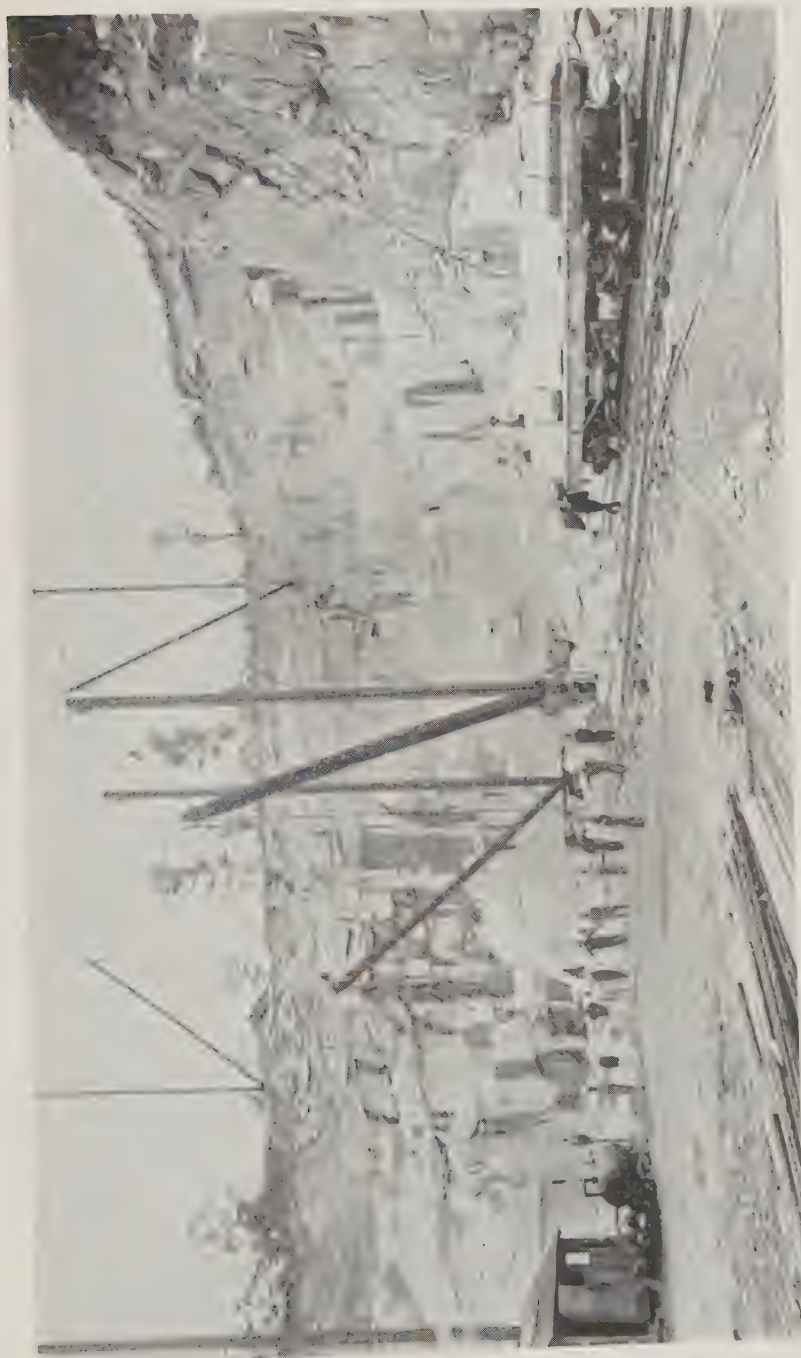
Fig. 6.—Granite quarry, Concord, New Hampshire, showing joint planes. Photo. by the Kimball Photographic Company, Concord, New Hampshire.
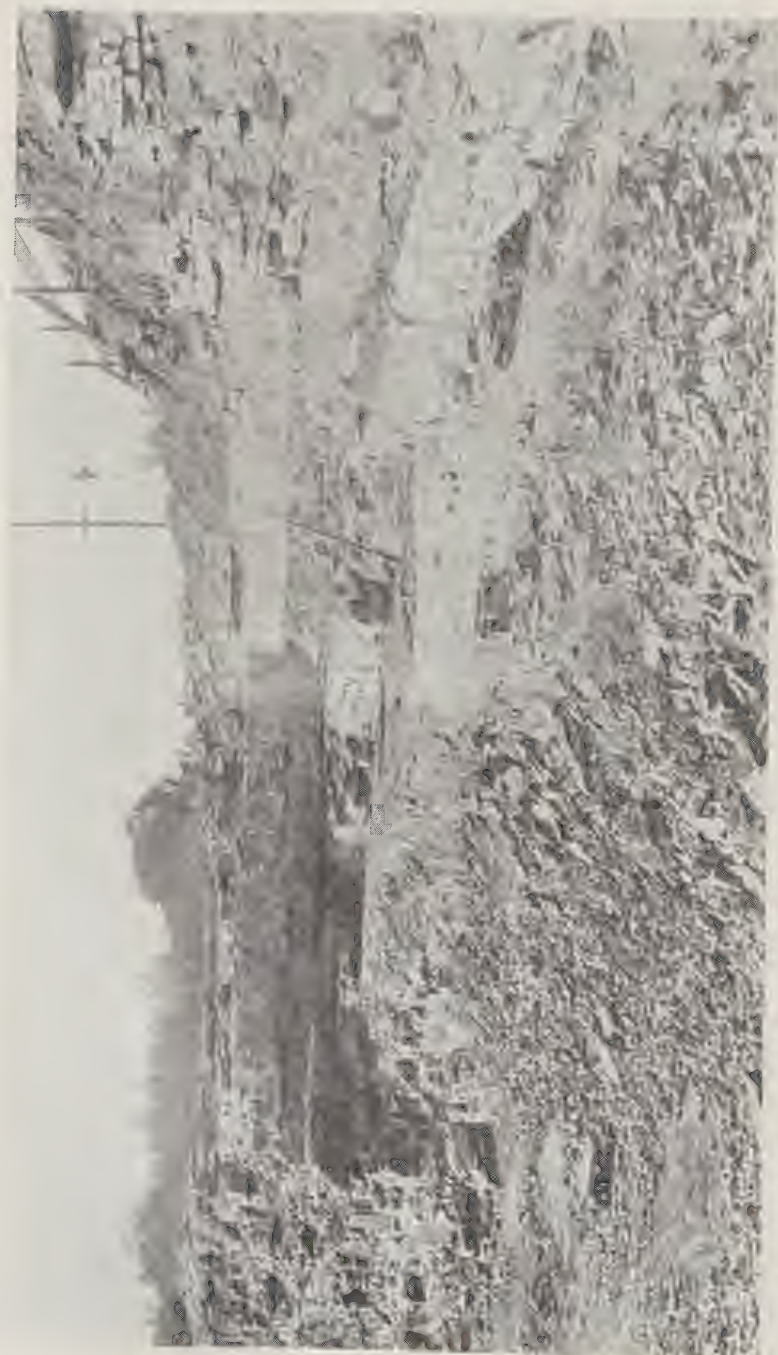
Fig. 17—Niagara limestone, Rochester, New York. Eiker quarry, looking south in southeast corner of the quarry.
Photo by H. L. Fairchild.

nearly at right angles to the cooling surfaces. In the marble deposits a considerable amount of heat was involved in their calcitization. As the temperature again falls to normal, joint planes are formed. There is always a large diminution in volume during the dolomitization of any limestone. Joint planes result also from compressive or tortional strain. Each strain resolves itself into two components which produces two sets of joints that intersect at an angle of about 90° and form an angle of 45° with the direction of the strain. W. O. Crosby recognizes vibratory strains as capable of producing joints. (See Fig. 16.)

Bedding planes correspond in the sedimentaries to the natural divisions that separate the successive layers into blocks of varying thickness. If these blocks become too thick

Fig. 18.—Jones Brothers quarry, Barre, Vermont, showing rift and grain of the granite blocks. Photo. by C. H. Richardson.

difficulties may be encountered in quarrying. If the blocks are too thin there is a large amount of waste in the handling of the stone because their thickness will not meet specified requirements. In case a paving stone only is desired extremely thin beds may be advantageous. In granite masses these planes are parallel with the quarry floor. When the

Fig. 19.—Niagara limestone, Lockport, New York. Watson quarry near crest of escarpment, looking southwest. The derrick stands on firm glaciated surface. Pre-glacial weathered stratum at 1½ ft. Photo. by H. L. Fairchild.

blocks are comparatively thin the stone is spoken of as having a sheeted structure. The position of these beds exerts a profound influence upon the quarrying of the stone. (See Fig. 17.)

Rift and Grain.—Every block of stone quarried must have three dimensions, and so there are three directions along which stones split with more or less ease. Quarrymen everywhere take advantage of these directions in working the stone into uniform blocks.

The most pronounced of these directions is usually parallel with the direction of the major joints. It is generally called the rift. In the igneous rocks it is often parallel with the quarry floor or with the sheets themselves where a sheeted

RIFT

HEAD
GRAIN
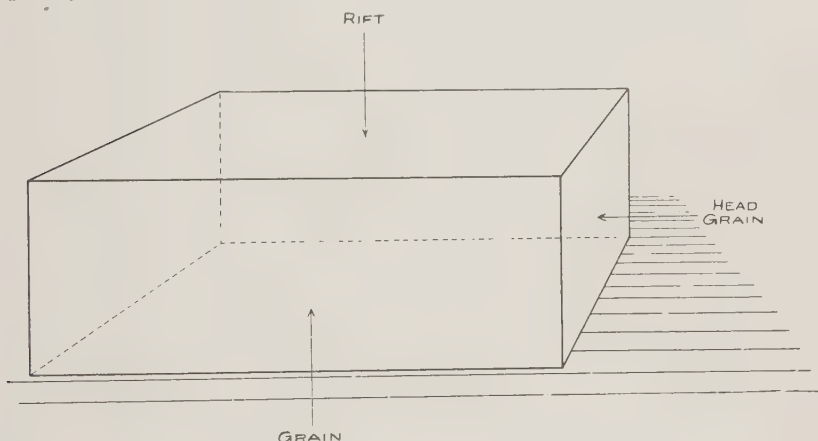
GRAIN

Fig. 20.—Drawing to explain rift and grain. Drawing by C. H. Richardson.

structure is pronounced. In the sedimentaries the rift is often parallel with the planes of sedimentation. (See Figs. 18 and 19.)

The grain is at right angles to the rift. The third direction is called the end grain or the head grain. A stone may work easily in lines parallel with the first two of these directions but the head grain may be so poor that regular rectangular blocks can be quarried only with great expense. (See Fig. 20.)

In the granite quarries in Vermont the term lift is often used for the first of these directions, rift for the second and grain for the third. (See Fig. 21.)

According to T. Nelson Dale the rift in granite is an obscure microscopic foliation which may be either vertical, or nearly

so, or horizontal, along which the stone splits more easily than in any other direction. The grain is a foliation in a direction at right angles to the rift along which the rock splits with a facility second only to that of the fracture along the rift.

J. F. W. Carpenter attributed rift to a parallel arrangement of the various mineral particles in a building stone. R. S. Tarr in his paper entitled "The Phenomena of Rifting in Granite," states that rift consists of microscopic faults, most of which meander across feldspar and quartz alike, although some go around the quartz particles rather than across them. In the feldspars rift usually follows the cleavage. These minute faults are lined with microscopic fragments of the
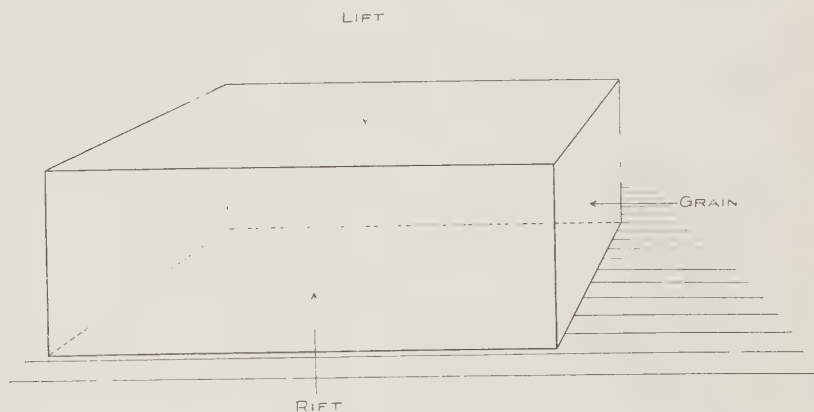
Fig. 21.—Drawing to explain lift as often used by Vermont granite quarrymen. Drawing by C. H. Richardson.

minerals they traverse and some of them send off short, minute diagonal fractures on either side. In the orbicular granite of Craftsbury, Vermont, the rift usually passes around the orbules rather than across them. The rift also does not traverse the basic dikes associated with the granites in the Jones Brothers quarry, Barre, Vermont, or the quarries of the Woodbury Granite Company on Robeson Mountain, Woodbury, Vermont.

G. I. Finlay in his paper entitled "The Granite Area of Barre, Vt.," states that the pronounced cracks which seem to cross from one crystal of quartz to another, without interruption, are an indication of pressure phenomena in the magma after its consolidation.

The presence of good rift and grain is an important factor

in the stone industry, for it materially reduces the cost of production of the finished product.

Compression.—Compressive strength in building stones depends upon the mineral composition, the size of the individual constituents and their state of aggregation. The tests are made with one inch, or five inch, cubes and stated in terms of pounds per cubic inch. The granites because of their oft interlocking crystals and the small interstitial spaces between the individual minerals have a high compressive strength. In good granites it varies from 15,000 lb. to 33,000 lb. to the cubic inch. In the marbles desired for structural work it varies from 13,000 lb. to 17,000 lb. to the cubic inch. Some of the dolomites, however, like those of Staten Island, N. Y., reach 24,000 lb.

Transverse Strength.—This is the load which a bar of stone, supported at both ends, is able to withstand without breaking. It is measured in terms of the modulus of rupture, which represents the force necessary to break a bar one inch cross section, resting on supports one inch apart, the load being applied in the middle. Stones in buildings are more apt to be broken transversely than crushed.

THE WEATHERING OF BUILDING STONES

The term weathering of building stones embraces all the chemical, mineralogical and structural changes that a stone undergoes when exposed to the destructive influences in the atmosphere. It involves something more than the ordinary changes effected in rock masses in the processes of normal disintegration. The destructive agencies may be catalogued as chemical and mechanical. (See Figs. 22 and 23.)

Chemical.—Pure water has but little if any solvent effect upon building stone. Water is seldom pure. It carries dissolved oxygen and carbon dioxide. It partially dissolves the more soluble materials with the liberation of colloidal silica, and the formation of the carbonates of calcium, magnesium, iron and the alkalies. The lime, magnesia, alkali salts and much of the dissolved silica remain in solution and are washed away. The iron carbonate is unstable. In its oxidation it forms the visible rusty coating or precipitate of ferric hydroxide that renders buildings once beautiful now unsightly.

According to W. P. Headden the solutions formed by the decomposition of the feldspathic rocks show a far greater change in the insoluble minerals than is apparent to the

casual observer. He treated orthoclase for a considerable period of time with water charged with carbon dioxide and obtained a solution which upon evaporation gave a residue that carried over 40 per cent of silica.

Another phase of the process is represented in the hydration of the undissolved residues. The iron minerals form limonite, the feldspars are transferred into kaolinite, and the magnesium minerals pass into talc or serpentine. This double process of solution and hydration is accompanied by an increase in volume which may assist in effecting disintegration.

Fig. 22.—Ovoidal block of fine statuary granite produced by weathering. Redstone quarry, Westerly, Rhode Island. By courtesy of the U. S. Geological Survey.

According to J. Hirschwald the solvent effect of pure rain water upon the compact, fine grained, Solenhofen limestone would give a reduction in volume of 0.85 millimetre in a century.

One decidedly injurious constituent in the atmosphere results from the large consumption of coal. The fuel often carries sulphur in combination with iron as the mineral pyrite. In the combustion of the coal the sulphur is burned to sulphurous acid which ultimately becomes sulphuric acid. This corrosive dissolves out the lime as calcium sulphate

which may crystallize as gypsum and in doing so assist in the disruption of the surface layers of building stone. The acid also attacks the mortar and cement with which the blocks of stone, terra cotta, or brick are bound together in the finished structure. This effect is often observed in the upper courses of chimneys. Nitric acid, hydrochloric acid and

Fig. 23.—Polished slab of biotite granite, showing a dead seam. Photo. by C. H. Richardson.

ammonia have also been observed in the atmosphere. Their presence everywhere accelerates the decomposition of building stone.

Coal combustion without smoke consumption results in supplying the atmosphere with unburned carbon and tarry particles that give rise to the smoke nuisance of large manufacturing cities. Not only does the smoke soon render the building unclean or unsightly but it acts as a carrier or holder

of deleterious gases. In cities like London where fogs are prevalent countless particles of condensed moisture carry dissolved gases to the surfaces of stone structures and leave them there for many days to execute their work of corrosion. Snow often carries a higher percentage of gases than rain and the lodgment of snow upon the sides of buildings, ledges and moldings favors disintegration.

In cities scattered along coast lines and subject to salt laden sea breezes the sodium chloride increases the solvent action of water on carbonates and sulphates and aids also in the attack upon lime silicates.

Vegetation.—Vegetation exerts a profound influence in the decomposition of rocks. Microscopic algae, mosses and lichens find lodgment on buildings and aid in rock decay. They retain moisture and make the surface beneath them damp. Their rootlets and roots penetrate into the surface of rocks along the lines of least resistance as they expand in the process of growth. Their roots contain organic acids which serve as solvents for minerals. The limestones and marbles appear to suffer more than the granites from the invasion of lichens. According to E. Bachmann this penetration is made regardless of the cleavage planes in the calcite. In the field, rocks of great strength and durability are often covered with lichens.

Bacteria.—Even such low forms of life as bacteria materially influence the decomposition of rocks. They draw their nourishment from the nitrogen compounds brought down in storms and convert the ammonia into nitric acid which in turn serves as solvent for mineral substances.

Physical Agencies.—Building stones as a rule are low in their conduction of heat and in their elasticity. When heated they expand but their contraction may not be to normal. This permanent increase in dimensions is termed permanent swelling. Many tests have been made with rock bars 20 inches in length, heated from $32°F.$ to the boiling point of water and then cooled to normal temperature. The results obtained for granites were .009 inch; marble, .009 inch; limestones, .007 inch; sandstones, .0047 inch. Small as this expansion seems to be it profoundly affects the decomposition of rocks. According to J. D. Dana the influence of the sun's rays upon Bunker Hill monument causes a pendulum when suspended from the top to describe an irregular ellipse nearly half an inch in its greatest diameter. The shaft was erected of Quincy granite in 1825. It is 30 feet square at the base and 221 feet high.

Frost.—The lowering of the temperature in rocks below the freezing point of water causes the absorbed water to expand upon solidification. This expansion throws off small scales from the surface or may even fracture large blocks. According to James Geikie if a porous sandstone becomes thoroughly saturated with water and the temperature falls below zero the pressure of the expansive force as the water solidifies is equal to a column of ice one mile high. Building stones then in northern climates where the temperature often falls to zero are rapidly decomposed.

Friction.—The effects of friction in the constant abrasion of building stones is most pronounced on sidewalks. The undulations in the surface of the walks of many large cities illustrate the rapid wearing away of the softer portions of the rock mass and the greater resistance of the harder areas. The convexities and the concavities in the treads of many stairways in city hotels are evidences of this same type of abrasion. In some large libraries the only entrance is over a single threshold of sandstone which wears away rapidly with the daily visitations. Windows in sandstorm zones are often rendered non-transparent by the effects of wind-blown sand. This feature is especially noticeable in many of the western states. It has also been observed in many instances along the eastern coast of New England. In many cemeteries where markers and monuments face in the direction of the prevailing winds, the inscriptions become illegible from the same cause.

Induration.—When a building stone is first quarried it is saturated with quarry water. This facilitates the working of the stone and makes possible the loss of material by shipment when the stone is frozen. The quarry water holds in solution, or suspension, an appreciable amount of the cements that bind the individual grains together. Upon exposure to the atmosphere this moisture is drawn to the surface by capillary attraction and evaporated. The lime, iron, silica, and clayey matter are left as a cement protecting the exterior of the stone. Honing and rescouring of objects of art after the quarry water has evaporated tends to render the destruction of the stone more rapid. For the same reason blocks for massive structures should be so wisely selected that they will not need re-dressing.

Life.—The life of a building stone signifies the length of time that may elapse before the resulting stone structure will so discolor or disintegrate as to necessitate repairs. Some of our cities are replete with structures which contain blocks

of stone that appear dead within five years from the completion of the structure. A re-dressing of such a block renders a brighter appearance for only a brief time and is always unsightly. Such instances might be easily avoided by a judicious selection of the stone during the process of construction. The life varies widely with the different types. A. Julien has carefully studied these factors in many stone structures in New York City with the following results:

Coarse brownstone	5- 15 years
Fine-laminated brownstone	20- 50 years
Compact brownstone	100-200 years
Coarse fossiliferous limestone	20- 40 years
Coarse dolomitic marble	30- 50 years
Fine dolomitic marble	60- 80 years
Fine-grained marble	50-100 years
Granite	75-200 years
Quartzite	75-200 years

According to J. A. Howe the stone castles of the British Isles possess many blocks of stones whose tool marks have been perfectly preserved for more than 700 years. It would therefore appear that a home might be constructed of an iron free quartzite that would last for a thousand years.

Selection of Building Stone.—The following rules may be stated as an aid in selecting the better types of structural stone:

(1) Select a stone that will resist well wide ranges of temperature. The author has twice read a thermometer at 62° below zero in northern New England and 98° above zero is frequently recorded in the same field. The range of temperature which the stone must stand is 160°. The coquina of Florida and the hornblende granite of Syene, Egypt, would rapidly disintegrate in such environment.

(2) Select a stone that will stoutly resist the corrosive effects of the acids and gases of the atmosphere. Where large quantities of acid fumes are constantly distilled into the atmosphere a stone with a calcareous cement will disintegrate far more rapidly than one whose cement is silica.

(3) Select a stone with high compressive strength and elasticity.

(4) Select a stone with large resistance to abrasion.

(5) Select a stone that always shows a clean, fresh fracture.

(6) Select a stone that gives a clear ring when struck with a hammer.

(7)   Select a stone that is fine grained and of even texture.
(8)   Select a stone with low porosity.
(9)   Select a stone with a siliceous cement, if possible.
(10)   Season a stone for a year before setting it in its permanent position. Quarry owners will object to this method of procedure. Yet knowledge should be available of the relative life of the stone. If oxidizable sulphides are present, or the carbonate of iron, the stone will begin to disintegrate and change its color within a year from the time it is quarried.

METHODS OF TESTING BUILDING STONE

Color Test.—The purpose of this test is to ascertain the permanency of color in any building stone. All rocks containing the carbonate of iron or the sulphide of iron will suffer a change in color on exposure to the atmosphere due to an oxidation of the iron content.

The presence of sulphides may be detected in the laboratory by the hepar test. The effect of an artificial atmosphere in accelerating oxidation has been carefully worked out by J. A. Dodge. Rectangular blocks about an inch in diameter are dried in a water bath until all of the absorbed moisture is expelled. They are then placed on glass shelves in an airtight chamber with open bottles of concentrated HCl and HNO_3 in close proximity to MnO_2. The fumes from the acids together with the chlorine formed by the action of the HCl on the MnO_2 exert a powerful oxidizing and corrosive effect on the samples. After seven weeks the samples are removed, washed and the change in color noted.

Corrosion Test.—This test is useful for all calcareous rocks. Inch cubes are suspended in water and subjected at intervals to the action of washed carbonic acid gas. The experiment should be continued for six weeks. The specimen should then be removed, washed, dried and weighed. By this test limestones sometimes suffer a loss of more than 1 per cent of weight. Quartzites whose cement is silica and massive granites that show no effervescence with HCl, due to small calcite content, are not appreciably affected by the experiment.

Abrasion Test.—The resistance to abrasion can be estimated by grinding a small sample on a common grinding bed. Much depends however on the weight applied during the grinding and the constancy of the supply of crushed emery or sand used for the abrasive. Soft rocks like the limestones will wear away rapidly. If they contain hard spots they will not wear uniformly.

Absorption Test.—The tests to determine the absorptive power of building stones is perhaps the most important and conclusive but not always absolutely reliable.

To determine the absorption from a damp atmosphere J. A. Dodge placed the samples to be tested in the cells of a hot-water bath for several days. After the hygroscopic moisture of the samples was expelled the samples were desiccated over H_2SO_4 and weighed. They were then placed on glass shelves in a pan of water, covered with a tight cylinder and allowed to stand for seven weeks at a temperature ranging from 60 to 70 degrees F. and then weighed. The absorptive power varied from .03 per cent to 3.94 per cent.

The amount of absorption by soaking is generally determined by carefully drying and weighing 2-inch cubes, then immersing them in water in a porcelain dish until thoroughly saturated. The cubes are then removed and weighed. The percentage of absorption varies from .83 to 10.06.

Freezing Test.—The best method to pursue where possible is to subject the samples to repeated freezings and thawings and thereby determine the loss in weight. Where this test is found to be impractical inch cubes may be subjected to the influence of a boiling solution of Na_2SO_4 for half an hour and then allowed to dry. During the drying the absorbed salt crystallizes and expands. The process may be repeated for six or eight days. The experiment is not altogether reliable for the sulphate of soda may give rise to free Na_2O which weakens the cohesion of the sample.

Expansion and Contraction Test.—These tests are necessary that the builder may make proper allowance for expansion in parapet walls and similar situations, and because the tenacity of a stone is weakened by expansion and contraction.

The tests employed by the Ordinance Department of the U. S. Army consisted in placing 20 inch bars of stone in baths of water at 32°F., then in water at 212°F. and then cooling quickly in water at 32°F. Samples thus tested do not return to normal dimensions but show a permanent swelling.

Fire Resisting Test.—In the experiments carried out by J. A. Dodge the samples were heated in a muffle furnace to a red heat and then removed and cooled. The experiment was repeated. The samples were then heated to a dull redness and immersed in water. Most building stones will crack or crumble under such treatment and the test seems too severe for practical purposes. For other fire resisting tests see N. Y. State Mus. Bull. No. 100; p. 16.

Compression Test.—The sample to be tested is sometimes cut in 1-inch cube, sometimes 2-inch cube and sometimes in 5-inch cube. The smoothed faces are placed between steel plates and the pressure applied. The pressure is relieved at the first sign of breaking in the sample and the weight of pressure recorded. The resistance is increased with the increasing dimensions of the cubes tested. The resistance to compression of each type of building stone is given under its respective caption in the subsequent chapters.

Elasticity Test.—To determine the elasticity of a stone a sample 24-in. by 6-in. by 4-in. is selected. The power is applied from the ends and the compressibility measured with a micrometer. The stone shows a permanent set from which it does not recover.

Shearing Test.—In this test prisms of stone are supported at each end by blocks 6 inches apart and subjected to pressure applied by means of a plunger. The plunger has a face 5 inches in width and exerts a force in all directions. The strain is like that exerted in many parts of a building.

Specific Gravity Test.—The small sample to be tested is first weighed in air, then in water. The general formula is specific gravity $= \dfrac{W}{W - W'}$. This result multiplied by 62.5, the weight of a cubic foot of water, gives the weight of a cubic foot of any stone.

For a fuller description of the methods of testing building stone the reader is referred to pp. 457 to 483 inclusive in " Stones for Building and Decoration," by G. P. Merrill.

CHAPTER III

GRANITES

Definition.—A granite is a holocrystalline igneous rock whose essential minerals are quartz and orthoclase, usually with muscovite or biotite, or both, present, or hornblende, more rarely augite, or both. There is generally present a feldspar containing both sodium and calcium. If a body of granite subsequent to its crystallization has been subjected to sufficient pressure to produce schistosity, or parallelism of the ferromagnesian minerals, it is called by the quarryman a granite gneiss. As gneisses differ widely in their origin they are reserved for discussion under another caption.

Origin.—Granite is generally recognized to be of irruptive origin. It represents the crystallization of an acid magma under great pressure and at a dull red heat. The magma contained superheated water and came slowly from the zone of flowage in the interior of the earth toward the surface but did not flow out over the surface. Thousands of feet of overlying strata are necessary to prevent a rapid cooling of the mass and its extrusion upon the surface as lava, also " to resist its pressure by its own cohesion and powerfully to compress it by its own gravity." The presence of liquid carbon dioxide in the cavities of the necessary quartz is an indisputable proof that granite forms under great masses of supernatant strata. These terranes must be removed by erosion in order to bring the granite formation into view. The fact that granite contains minerals that lose their physical properties at temperatures exceeding a dull red heat is proof that it crystallizes at temperatures comparatively low. If the magma had been extruded upon the surface as lava it would have cooled so rapidly that few if any individual minerals would have formed and the product would have been a volcanic glass. Slow cooling is necessary for complete individualization. The study of many microscopic slides reveals the order of crystallization. If the accessory minerals apatite and zircon are possible in the magma they appear among the earliest solidifications. The ferromagnesian minerals crystallize before the feldspars, while quartz, which is the most acidic of

all the minerals in granite, is the last to solidify. Granite may also result from the metamorphism of feldspathic sediments.

Mode of Occurrence.—Granites occur in large batholiths that have dissolved the overlying rock masses and made them a part of their own composition; as laccoliths that have arched the overlying strata upwards; as bosses, stocks, sills and tortuous veins.

Name.—Granites are often named from the prevailing ferromagnesian minerals they contain. A granite containing muscovite would be called a muscovite granite; one containing biotite is known as a biotite granite; one containing both muscovite and biotite as a muscovite biotite granite. If a
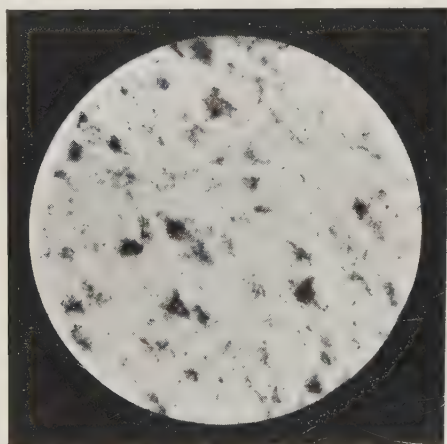
Fig. 24.—Polished disc of white granite, Bethel, Vermont. From quarries of the Woodbury Granite Company, Hardwick, Vermont. Photo. by C. H. Richardson.

granite contains hornblende it is called a hornblende granite; if it contains augite alone an augite granite. If both minerals are present it is called an augite hornblende granite. If tourmalines are present in considerable quantity displacing the normal ferromagnesian minerals it is called a tourmaline granite. Tourmalines may be formed by some mineralizing agency during magmatic crystallization or by pneumatolysis at the expense of mica and feldspar.

Economic Classification.—There are several different ways of classifying granites from an economic standpoint.

(1) If the classification is based upon color, it is dependent upon the color of the prevailing feldspar, or upon the effect

of the micas on the granite as a whole. The granite is called red if the orthoclase is red. Pink, if the orthoclase is pink or flesh colored. Green, if the effect of the feldspar and the
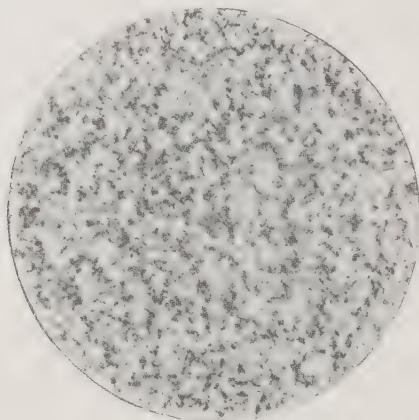
Fig. 25.—Polished disc of fine grained gray granite, Barre, Vermont. Photo. by C. H. Richardson.
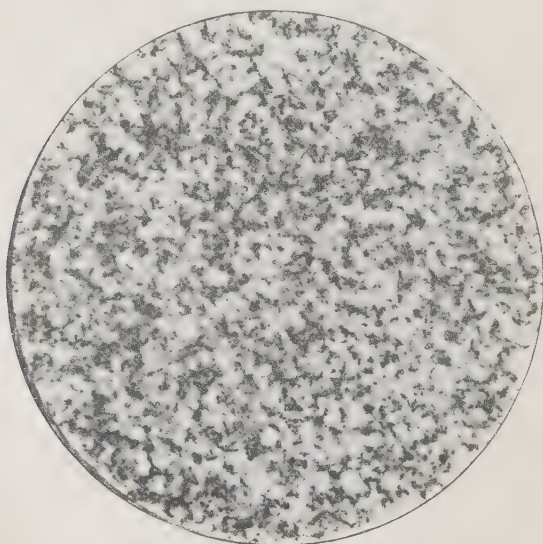
Fig. 26.—Polished disc of medium grained gray granite, Newport, Vermont. Photo. by C. H. Richardson.

ferromagnesian minerals combined produces that color. Gray, light or dark, dependent upon the amount and kind of mica that is present. (See Fig. 24.)

(2) The basis of classification may be made upon texture. If the crystals are exceedingly fine, less than .2 inch in diameter, the stone is called fine grained; if of medium size, between .2 and .4 inch in diameter, medium; if coarse, more than .4 inch in diameter, coarse grained; or if phenocrysts of appreciable size appear, the stone is called porphyritic. (See Fig. 25.)

Fig. 27.—Christian Science Church, Concord, New Hampshire, built of Concord granite. Photo. copyrighted by Kimball and Son, Concord, N. H., and published by their courtesy.

(3) These two features may be used together in classification. A fine grained red granite might be the result. A porphyritic green granite, or a medium grained gray granite. (See Fig. 26.)

(4) Granites are often classified in the commercial world from the standpoint of use. If a granite is better adapted for massive structures than any other use it is called a constructional granite. If its qualities render the stone better suited for cemetery work than any other it is called monumental or inscriptional. If it is well suited for base boards, panels and pillars where it is not exposed to the corrosive effects of the atmosphere it is called decorative. If the granite is sufficiently fine grained for excellent work in the construction of statues and statuettes it is called statuary granite. (See Figs. 27 and 28.)

Geographical Distribution.—The Appalachian belt presents many occurrences of granites arranged in a line practically parallel with the Atlantic Coast. A second belt is roughly parallel with the Pacific Coast. A third belt appears along the axis of the Rocky Mountains. It might be called the Cordilleran belt. A fourth area appears in the neighborhood of the Great Lakes between Lake Michigan and Lake Superior, and to the north of Lake Superior. Rather than discussing these occurrences by districts the author prefers to take up the more important states in alphabetical order.

AMERICAN GRANITES

California.—According to G. P. Merrill the first stone house in San Francisco was built out of stone brought from China. Later granite blocks were secured from Scotland and Quincy, Mass. In 1864 the granite quarries at Penrhyn and Rocklin in Placer county were opened up. This tract alone comprises some 680 acres. Blocks 100 feet long, 50 feet wide, and 10 feet thick have been quarried.

According to J. J. Jackson the Penrhyn stone is a fine grained hornblende granite susceptible of a good polish. He gives the mineralogical composition as quartz, orthoclase, plagioclase, hornblende, biotite, with accessory microscopic apatite and magnetite. The Rocklin stone is lighter in color for muscovite replaces the hornblende. Granites are also quarried in Sacramento County. (See Figs. 29, 30 and 31.)

Colorado.—The granite industry of Colorado is quite largely dependent upon the industrial development of the

Fig. 28.—Pediment, Wisconsin State Capitol, Madison, Wisconsin. Built of Bethel, Vermont, white granite. Carl Bitter, sculptor. Photo. by E. C. Nelson.

state. The cost of transportation is high for building stones both in an easterly and in a westerly direction. The author
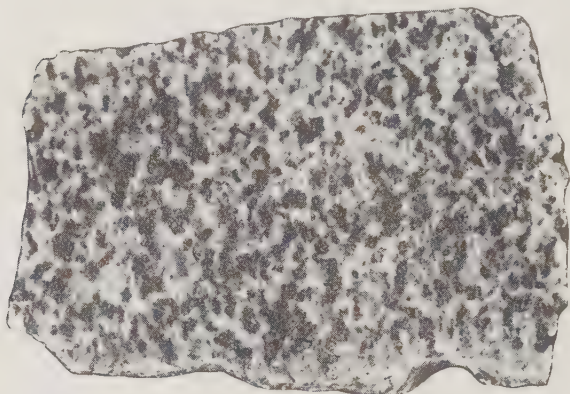
Fig. 29.—Polished slab of hornblende granite, Penrhyn, California. Photo. by C. H. Richardson.

Fig. 30.—Polished slab of light gray granite from near Granite Peak, Raymond, California. Photo. by C. H. Richardson.

has examined several quarries of fine grained gray granite at Georgetown and Lawson in Clear Creek County. These

granites takes a fine polish and are well suited for constructional work. A coarse red granite is quarried to some extent in Jefferson County at Platte Canon. A gray granite of superior quality is quarried at Beaver Creek, Gunnison County. The State Capitol at Denver was built of this stone. (See Fig. 32.)

Connecticut.—Granites are extensively quarried in five counties in Connecticut. These are Litchfield, Fairfield, Middlesex, New Haven and New London Counties. The

Fig. 31.—Declez granite quarry, Declez, San Bernardino County, California. Photo. by T. C. Hopkins.

granites are usually finer grained, lighter in color, than the granites of northern New England. Frequently Connecticut granites can be recognized by these ear marks.

The constructional granitic rocks of Connecticut are a medium to coarse biotite granite of medium reddish gray color quarried at Stonington; a medium to coarse biotite granite gneiss of reddish gray color quarried at Branford; a coarse biotite granite gneiss of dark reddish gray color

Fig. 32.—Colorado State Capitol, Denver, Colorado. Built of Beaver Creek gray granite. Photo. by C. L. McClure.

quarried at Branford; a medium biotite granite gneiss of reddish gray color quarried at Guilford; a quartz monzonite of fine grain and light gray color at Bristol; a coarse mica diorite gneiss of dark bluish gray color at Greenwich; granite gneisses are also quarried at Lyme, Norfolk, Roxbury and Torrington, Connecticut.

The monumental granite rocks are chiefly quartz monzonites. They are quarried at Waterford, Groton, Stonington and Thomaston. In color they are medium dark gray, medium greenish gray, slightly bluish gray and medium bluish gray.
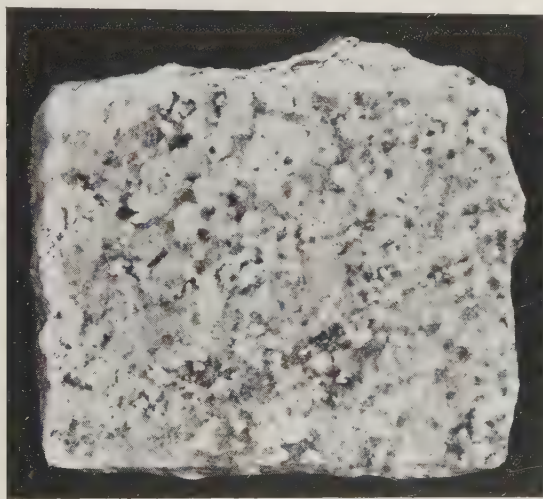
Fig. 33. — Polished slab of Stony Creek granite, Stony Creek, Connecticut. Photo. by C. H. Richardson.

Inscriptional quartz monzonites, shading in color from medium to dark gray are quarried at Groton, Stonington and Waterford.

Biotite granite gneisses, used for curbing and trimming, shading in color from a buff gray to a dark bluish gray, are quarried at Balton, Glastonbury and Waterford. (See Fig. 33.)

Delaware.—The granite industry of Delaware is restricted to a few gneissoid rocks in the neighborhood of Wilmington. Their use is for construction locally.

Georgia.—The granites of Georgia fall into two distinct classes;—The granite proper and the gneissoid granites. They are usually fine grained, even textured, susceptible of a

good polish and suited for both construction and monumental work. The former class occurs in the Elberton-Oglesby-Lexington area, the Fairburn-Newman-Greenville area and the Stone Mountain area. The latter class occurs in the Lithonia-Conyers-Lawrenceville area. A coarse grained, porphrytic, biotite granite occurs in the Sparta area.

Maine.—The granite industry of Maine may be said to have its center in Penobscot and Blue Hill bays and the islands encircling them. More than 130 quarries and prospects have been opened and most of these are along the seaboard, on

Fig. 34.—King Chapel, Bowdoin College, Brunswick, Maine. By courtesy of Bowdoin College.

islands, or near bays or navigable rivers. This area which includes the major portion of the granite industry of the state comprises some 1,200 square miles. Thirteen counties produce either true granites or gneissoid granites. These are Cumberland, Franklin, Hancock, Kennebec, Knox, Lincoln, Oxford, Penobscot, Piscataquis, Somerset, Waldo, Washington and York. It is only the quarries that the author has personally visited that will be described. For a full and complete description of all the quarries and prospects within the state the reader is referred to Bulletin 313 U. S. Geological Survey, " The Granites of Maine," by T. Nelson Dale.

Cumberland County

The Grant quarry is situated less than three miles from the city of Brunswick. It represents a biotite granite of medium gray shade and of even texture. The Chapel of Bowdoin College was built of this stone. (See Fig. 34.)

The Freeport quarry is situated within one mile of Freeport station on the Maine Central Railroad. It represents a fine grained, even textured granite, which bears both muscovite and biotite with the latter mineral predominating over the former. The polished tanks at Poland Springs and the front of the Maine Building at the Chicago Exposition are of this stone.

Fig. 35.—Allen quarry, west side of Somes Sound, Mount Desert, Maine, showing lenticular sheets crossed by a vertical diabase dike, faulted on the fourth sheet from the bottom of the quarry. By courtesy of the U. S. Geological Survey.

The Pownal quarries are situated within three miles of Yarmouth Junction on the Maine Central and Grand Trunk Railroads. The stone is a light gray, biotite granite, of even texture and well adapted for monuments and constructional work.

4

Franklin County

In Franklin County the quarries at North Jay yield a white granite which in reality is of a very light gray color. It is a biotite-muscovite granite. The stone is shipped largely to the states west of New England. The Chicago and Northwestern building in Chicago is from the North Jay quarries.

Hancock County

In Hancock County the Black Island quarries are situated on Black Island. Two types of granite occur on the island. One is a pale pinkish gray, even textured granite, and the other a somewhat coarser, grayish pink biotite granite.

Fig. 36.—Crabtree and Harvey quarry in Sullivan, Hancock County, Maine, showing irregularity in the thickness of sheets owing to their lenticular form; also 9 black knots. By courtesy of the U. S. Geological Survey.

The McMullen quarry is in the town of Mount Desert. The stone is a biotite granite of grayish buff color and coarse grained texture. The United States Mint Building in Philadelphia is of this granite. There are many other quarries in Mount Desert but the most of them are biotite granites. The

Graves Brothers quarry, however, represents a hornblende granite that is used only locally.

There are many quarries in the town of Sullivan. These, with two exceptions, are biotite granites of gray color and medium texture. The exceptions are the Sinclair quarries which represent a very dark quartz monzonite which contains
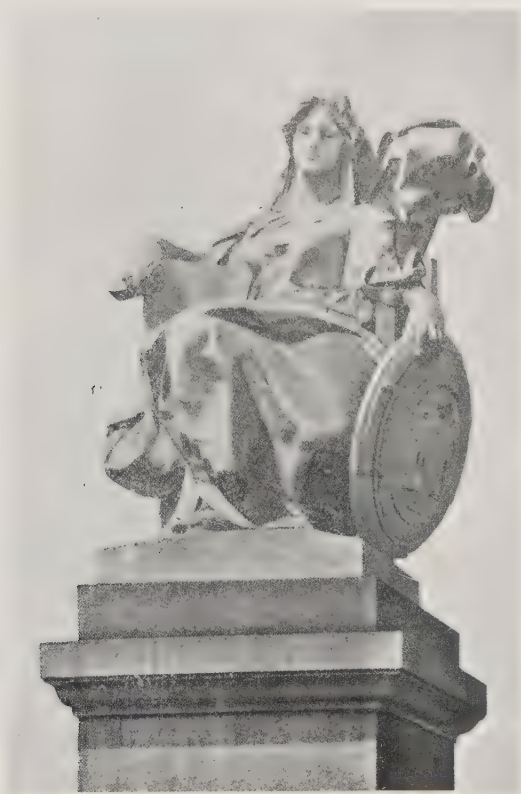
Fig. 37.—Carving from the light gray, fine textured, biotite-muscovite granite from the Stinchfield quarry, Hallowell, Maine, showing adaptation to delicate sculpture. By courtesy of the U. S. Geological Survey.

both hornblende and biotite, and the Pettee quarries which consist of a mica-quartz diorite of dark gray color and medium texture. These two quarry products are classified in the trade as black granites. (See Figs. 35 and 36.)

Kennebec County

In Kennebec County the granites of Hallowell and Augusta have been known since 1825 when capital turned from Quincy, Mass., to Hallowell, Maine. The granite is of light gray color and fine texture, with a few phenocrysts of feldspar. It is a biotite-muscovite granite that has long been justly celebrated for its beauty and fine working qualities. The Albany Capitol, Hall of Records, N. Y., is from the Stinchfield and Longfellow quarries, and the General Slocum monument at Gettysburg, Pa., is from the Tayntor quarry. (See Figs. 37 and 38.)

Fig. 38.—Granite quarry, Hallowell, Maine, showing thickness of sheets. Photo. by C. H. Richardson.

Knox County

The Fox Island granite comes not only from Fox Island but Vinalhaven, Hurricane, and several adjacent islands. The majority of the granite is a pinkish-buff, medium gray color, coarse, even texture. The Palmer quarries, the Pequoit quarries and those in the village of Vinalhaven are fine textured. These are essentially biotite granite, but the Pequoit quarries represent a biotite-hornblende granite and

the Bodwell black granite is an olivine norite of black color and fine texture. (See Figs. 39 and 40.)

Lincoln County

(See Fig. 41.)

Oxford County

The Fryeburg granites are in Oxford County. They are muscovite-biotite granites of light gray color and medium texture. The Woodstock granite from the Bryant quarry is a quartz-mica diorite of bluish-white color and medium texture.

Fig. 39.—Hurricane Isle quarry, Knox County, Maine, showing eastern end. By courtesy of the U. S. Geological Survey.

Penobscot County

The granite of Hermon Hill, Penobscot County, is commercially classified as a black granite. In reality it is an altered diabase porphyry with phenocrysts of black hornblende. The stone is of a dark green color and of fine texture. The product finds its best use in dies, memorial tablets, wainscoting and monumental works. Lord Hall at the University of Maine carries this stone.

Washington County

The rocks commercially classified as granites in Washington County differ widely in mineral composition and the uses to which they are well adapted. The Pleasant River quarries in the town of Addison produce a hypersthene-olivine gabbro of black color and medium texture; the Thornberg quarries, also in the town of Addison, produce one granite identical with the preceding, and another which contains labradorite and no olivine. The town of Baileyville furnishes a dark gray norite of brilliant luster. The town of Calais produces a black granite which is a quartz diorite bearing a little musco-

Fig. 40.—Sands quarry, Vinalhaven, Maine, showing the curvature of the sheets, the intersecting joint face and the north 10° east channelling along the cut-off. By courtesy of the U. S. Geological Survey.

vite and biotite. This stone is of fine, even texture. It also produces a norite of greenish-black color and even texture; a mica-quartz diorite of dark gray color; a dark red granite speckled with pale green shades; a biotite granite of bright pinkish color. The red granite in the two corner wings of the American Museum of Natural History in New York is from the Redbeach Granite Company's quarry in the town of Calais. The Maine Red Granite Company of Calais possesses

the most extensive plant for cutting and polishing granite within the state.

The " moose-a-bec red " granite of Jonesport, Hardwood Island, consists of smoky quartz, reddish orthoclase, white oligoclase and black biotite. The stone is of coarse, even-grained texture. It is used in the lower course of the new building of the College of Agriculture, Syracuse University.

York County

In York County the Bennett quarries produce a quartz-mica diorite of greenish, dark gray color and even texture.

Fig. 41.—Round Pond black granite quarry, Bristol, Lincoln County, Maine, showing the quartz diorite sheets crossed by a 2-foot 4-inch dike of coarse pegmatite. By courtesy of the U. S. Geological Survey.

The Spence and Coombs black granite is a gabbro of dark olive-brownish color and ophitic texture. The Ricker quarries produce a biotite granite of light gray color and coarse texture.

Maryland.—The chief granite quarries in Maryland are situated in Baltimore County, and the product is known as the Woodstock granite. It is a biotite granite of light gray to dark gray color, of medium texture and susceptible of a fine

polish. A considerable amount of the dark gray Baltimore gneiss is quarried and used extensively for purposes of rough construction in the city of Baltimore and vicinity. (See Figs. 42 and 43.)

Massachusetts. —In considering the numerous granites of Massachusetts only those quarries will be described that have been visited by the author. For a fuller description of all the granites of the state the reader is referred to Bulletin 354, U. S. Geological Survey, "The Commercial Granites of Massachusetts, New Hampshire and Rhode Island," by T. Nelson Dale.

Fig. 42.—Granite quarry near Woodstock, Baltimore County, Maryland. By courtesy of the Maryland Geological Survey.

Milford.—Milford is situated in Worcester County in the eastern half of the state. According to B. K. Emerson and J. H. Perry there is a great granite area of a constant type that extends across Massachusetts and Rhode Island. The Milford granite is a compact, massive rock, somewhat above medium grain and of light color. The light fresh color of the feldspar and the blue of the quartz give it in some places a slightly pinkish tint. It is now much used as a structural stone under the name of pink granite. It is a biotite granite. There are

twelve or more of these quarries in and around Milford. (See Figs. 44 and 45.)

Quincy.—The Quincy granite area falls in the towns of Quincy and Milton in Norfolk County. The main granitic mass was intruded into overlying slates which in places have been completely eroded. T. Nelson Dale epitomizes this granite as a riebeckite-aegirite granite. Riebeckite is a variety of hornblende which occurs in crystals longitudinally striated and with perfect prismatic cleavage. Aegirite is a variety of pyroxene which occurs in prismatic forms often bluntly terminated and greenish in color. Both of these minerals

Fig. 43.—McClenahan granite quarry, Port Deposit, Cecil County, Maryland, showing ideal location with reference to railway and water transportation. By courtesy of the Maryland Geological Survey.

are rich in sodium and iron. The granite shades from a medium gray to a dark purplish gray and a very dark bluish gray color. It grades from a medium to a coarse grain and is susceptible of a fine polish.

This high polish is due in part to the absence of mica whose perfect basal cleavage interferes with a high polish, and in its place as a ferromagnesian mineral the varieties of hornblende and pyroxene already noted. A peculiar variety of

Fig. 44.—Polished slab of pinkish granite, Milford, Ma   ac't   . .
Photo. by C. H. Richardson.

Fig. 45.—United States Post Office, New York City, built of granite
from Milford, Massachusetts. By courtesy of the Webb Pink Granite
Company, Worcester, Massachusetts.

this granite is commercially known as the " Gold leaf." The stone is of medium texture, bluish green gray color with yellow spots that are caused by a limonite stain. Quincy granite is one of the most popular monumental stones in the world. It is used also for constructional work. When fashioned into polished pillars or colonnades it is without a peer in its decorative effect. It was from this granite that Bunker Hill monument was erected in 1825. (See Figs. 46, 47 and 48.)

Fig. 46.—Ball of polished Quincy granite from the Wigwam quarries, Quincy, Massachusetts. Diameter 76 inches. Weight 22,010 pounds. By courtesy of the U. S. Geological Survey.

Rockport. — The Rockport quarries are situated on the eastern and northern part of Cape Ann. According to N. S. Shaler the entire cape is of granite traversed here and there by diabase dikes and occasionally by quartz porphyry dikes. There are two varieties of Rockport granite. One is a horn-

blende granite of medium gray color and spotted with black. It is of medium to coarse texture. The other is also a hornblende granite. It is of dark olive gray color, spotted with black and commercially known as green granite. Two other varieties of building or decorative stone are quarried on a small scale on Cape Ann. One is an augite syenite and the other an altered diabase porphyry. (See Figs. 49 and 50.)

Fig. 47.—Dell Hitchcock granite quarry, North Commons, Quincy, Massachusetts, from the west side. By courtesy of the U. S. Geological Survey.

Minnesota.—According to N. H. Winchell more than half of the state is underlaid by that series of crystalline rocks to which granite belongs. In the northern part of the state there are many outcrops of a light gray granite that have

remained unopened on account of the absence of settlements and the difficulties of transportation.

East St. Cloud.—These quarries were opened in 1868 and the product was used in the construction of the Custom House and Post Office in St. Paul. Two types of stone are present. One is of gray color, fine and close texture. The other is a red granite of much coarser grain. The ferromagnesian minerals present are hornblende and chlorite. A similar granite to the red variety of St. Cloud is found at Watab in Benton County. (See Fig. 51.)

Missouri.—Large masses of granite appear in Missouri in Iron, Madison and St. Francois Counties but none of them are extensively worked, save the red granite of Graniteville
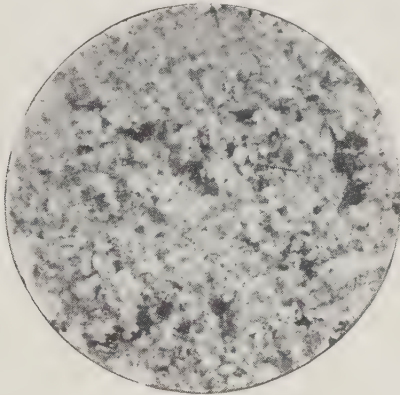
Fig. 48.—Polished disc of light Quincy granite, Quincy, Massachusetts. Photo. by C. H. Richardson.

and the syenite which finds its way into the St. Louis and Chicago markets. This stone admits of a good polish and is well suited for monumental work.

Montana.—Lewis and Clarke County is the largest producer of granite in the state. This county furnishes light gray biotite granites and coarse, gray, hornblende-mica granites. Difficulties in transportation enter into the problem of the commercial development of these desirable products.

New Hampshire.—The granites of New Hampshire are widely distributed in the central and eastern part of the State with a few less important quarries of granites and gneisses in the western part. The author has examined either outcrops or quarries and made microscopic sections of samples

collected in Allentown, Concord, Conway, Enfield, Farmington, Fitzwilliam, Grafton, Groton, Hanover, Hooksett, Lebanon, Manchester, Milford, Marlboro, Pelham, Salem, Sunapee and elsewhere. Only a few of the more important granites from a commercial standpoint can be described.

Fig. 49.—Deep Pit quarry of Rockport Granite Company, near Bay View on Cape Ann, Massachusetts, looking north. By courtesy of the U. S. Geological Survey.

Concord.—The Concord granite is according to G. P. Merrill one of the most important granites of the United States. It is a muscovite-biotite granite of medium gray color and fine to medium texture. It ranks fourth among the white granites of America. In the order of decreasing whiteness the list is Bethel, Vermont; North Jay, Maine; Hallowell,

Fig. 50.—Post Office, Boston, Massachusetts, built of Rockport gray granite. Rockport, Massachusetts. By courtesy of the Rockport Granite Company.
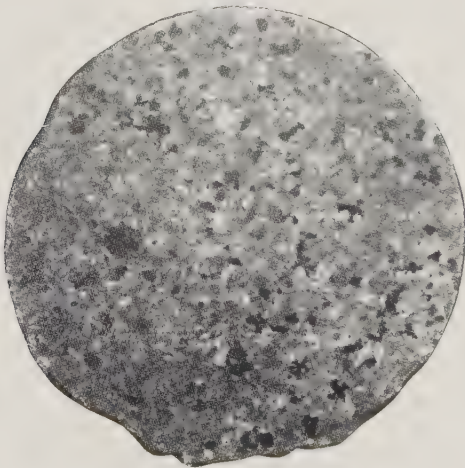
Fig. 51.—Polished disc of hornblende granite. East St. Cloud, Minnesota. Photo. by C. H. Richardson.

Fig. 32.—Granite quarry, Concord, New Hampshire, showing rift and grain of the stone. Photo. by the Kimball Photographic Company, Concord, New Hampshire.

Fig. 31.—Granite quarry, Concord, New Hampshire, showing thickness of sheets and work of the channelling machine. Photo by the Kimball Photographic Company, Concord, New Hampshire.

Maine; Concord, New Hampshire. (The author has in his possession a five-inch polished disc of what is catalogued by the owners of the stone as "A New Barre Granite,' Concord, New Hampshire. This disc shows a rapid deterioration from the oxidation of the sulphur and iron content. The presence

Fig. 54.—Polished cylinder of green granite, North Conway, New Hampshire. Photo. by C. H. Richardson.

of sulphur is further substantiated by an analysis of a sample of Concord granite made by Sherman and Edwards and collected by W. O. Crosby which showed .27 per cent. sulphur. (See Figs. 52 and 53.)

The sample cited may, however, be from near the contact with the associated gneisses that are far more likely to carry accessory pyrite.)

Conway.—The Conway quarries are situated near North Conway in Carroll County. The quarry sites are upon both the east and west sides of the Saco valley. According to T. Nelson Dale the geological features of general interest in the Conway granites are their marked rift and grain, the rift being

uniformly horizontal and the grain vertical; the contiguity of a yellowish green biotite-hornblende granite to a pink biotite granite at Redstone. These two granites now side by side represent originally different materials. The feldspars
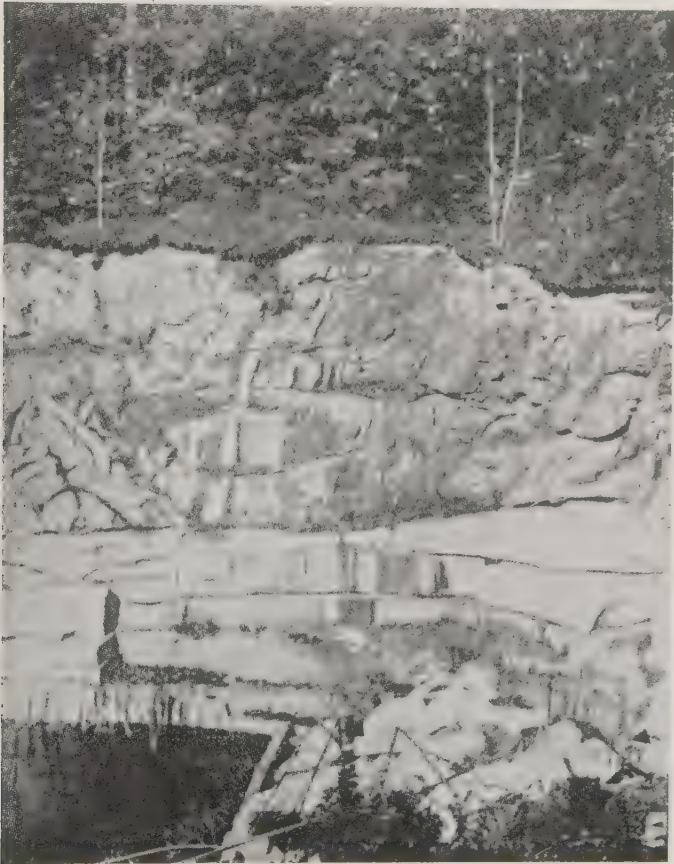
Fig. 55.—Contact of granite and overlying gneiss at the Milford Granite Company's quarry, Milford, New Hampshire, looking west. By courtesy of the U. S. Geological Survey.

of one are tinted by the limonitization of the associated allanite and hornblende and of the other by the hematitization of magnetite or ferrite. (See Fig. 54.)

Milford.—The village of Milford is situated on the Souhegan River. The most of the quarries lie in a southerly direction

some four miles from the village. This granite area is unique in one respect for it represents a granitic mass now overlaid by a granite gneiss that was once a granite of an earlier period of intrusion, and subsequently metamorphosed into a gneiss. The granites are quartz monzonites of light, medium, and dark gray hues, and of fine even texture with one exception. (See Fig. 55.)

Sunapee.—The structural and ornamental stones of the area of Lake Sunapee consist of a biotite-muscovite granite which is light gray in color and of fine texture, and a black granite which is a quartz-mica diorite of dark bluish gray color and fine texture. The last stone when polished appears black,
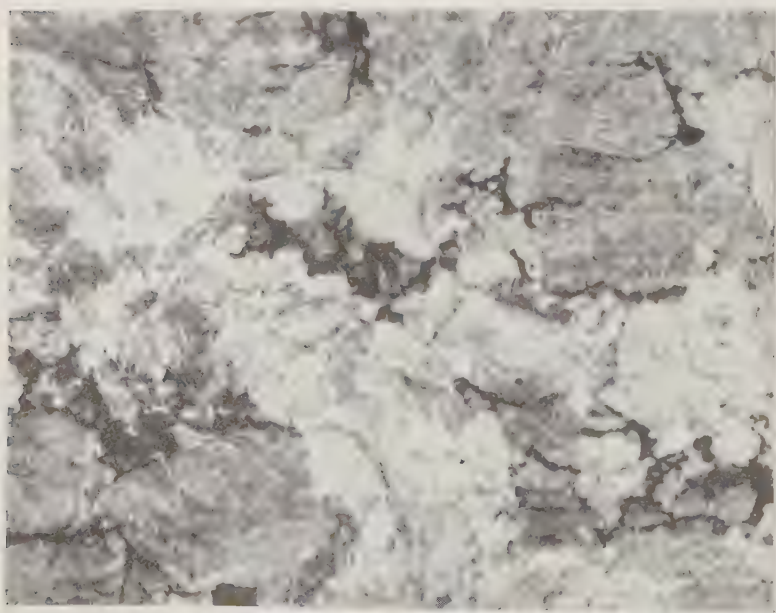
Fig. 56.—Pompton pink granite, Pompton, New Jersey, showing pegmatitic characteristics. By courtesy of J. Volney Lewis.

mottled with white, and is largely used for monumental work.

New Jersey.—The granitic and gneissoid belt of rocks traverses the state in a northeasterly and southwesterly direction. Only a few quarries appear to have been worked to any considerable extent. The best known of these granites are the Pompton pink granite which is coarse grained; the Dover light gray granite which is gneissoid; the Cranberry

Lake white granite which is fine grained and the German Valley granite which is of medium texture. (See Figs. 56 and 57.)

New York.—Although the state of New York contains a vast area of igneous rocks it has never been an important

Fig. 57.—St. Paul's church, Paterson, New Jersey, built of Pompton pink granite. By courtesy of J. Volney Lewis.

factor in the granite industry. The best known granite of the present time comes from the Island of Picton in the St. Lawrence River. It is a fine grained pink granite, well adapted to structural and monumental work. It dresses well and is susceptible of a fine polish. The new wing of the American Museum of Natural History in New York is of this stone. (See Fig. 58.)

Grindstone Island, N. Y., also in the St. Lawrence River, furnishes a deep red coarsely grained crystalline granite, which is susceptible of a good polish and is used for monumental work. It is a hornblende granite. The two polished columns in the Senate Chamber at Albany are of this stone. (See Fig. 59.)

The Keeseville granite which is some five miles from Ausable Chasm in the Champlain valley is a norite. It contains the feldspar labradorite, and the pyroxene, hypersthene. The hypersthene sometimes appears as black knots which ultimately lead to a discoloration of the stone due to the oxidation of the iron content of the hypersthene. Where this

mineral is uniformly distributed throughout the rock mass the stone takes a fine polish and is well suited for decorative interior work.

North Carolina.—According to T. L. Watson about one-half of the entire area of the state is covered by irruptives, although the granites are not extensively worked. From a mineralogical standpoint Watson makes the following classification:

Fig. 58.—Polished block of red Picton granite with drove margin, Picton Island, New York.   Photo. by C. H. Richardson.

1. Biotite granite, with or without muscovite, and including most of the areas of the state, such as Mount Airy, Dunns Mountain and Graystone.

2. Hornblende-biotite granite, including the granites of northern and southern Mecklenburg County.

3. Muscovite granite, with or without biotite, as Warren Plains in Warren County.

4. Epidote granite from Madison County.

Oklahoma.—The Arbuckle and Wichita Mountains furnish a few granites of commercial importance. The Arbuckle granite is pink in color and of coarse texture. It is used for structural work. The Wichita granite varies from a light pink to a dark red color and ranges from a fine to a coarse texture.

Pennsylvania.—Although this state ranks among the first in production of building stones, it appears to produce little if any true granite. A dark hornblende gneiss has been quarried in the vicinity of Philadelphia and used locally for purposes of construction since the days of William Penn.
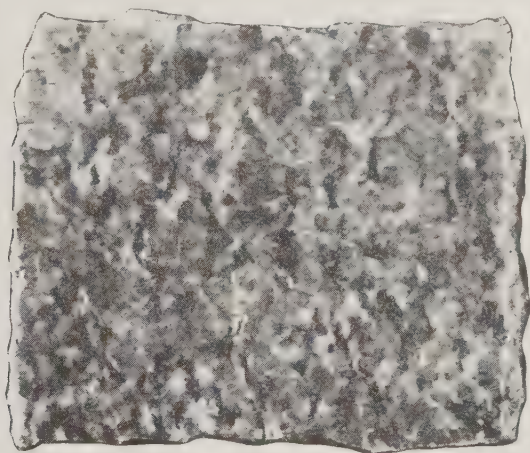
Fig. 59.—Polished slab of red granite, Grindstone Island, St. Lawrence River, New York. Photo. by C. H. Richardson.

Gneiss is also quarried in Chester, Delaware County, and used both for construction and foundation work.

Rhode Island.—The quarries at Westerly, Rhode Island, are the only ones in the state visited by the author. The geological features here in certain respects are similar to those at Milford, New Hampshire. In early geological times an acid intrusive of granitic composition invaded the terranes bordering the Atlantic coast. After the crystallization of this granite it was subjected to compressive stresses sufficient to crush, elongate and re-arrange the minerals of the earlier granite into a gneiss. The gneiss was later invaded by the

present granite stock from which the fine statuary material is now derived. (See Fig. 60.)

T. Nelson Dale cites the following order of geological events transpiring about Westerly: (1) A finely banded biotite gneiss forms the surface. (2) Intrusion by the red granite of the hill northwest of Westerly and by the gray granite of Niantic. (3) Metamorphism of the red and gray granite

Fig. 60.—Joh monument cut from Westerly, Rhode Island, granite and erected in Baltimore, Maryland. Photo. by C. H. Richardson.

converting it about Niantic into a porphyritic gneiss. (4) Intrusion of the Westerly and Niantic fine granites, in some places into the earlier banded biotite gneiss, in others into the more or less altered granite gneiss. (5) Pegmatite dikes traverse both the Westerly granites and the Sterling granite gneiss. (6) A diabase dike traverses alike the Westerly granite, the Sterling granite and the pegmatite dikes.

Three different types of granite are pronounced at Westerly. (1) The Westerly white statuary granite is a quartz monzonite of pinkish or buff medium gray color and fine even texture. (2) The blue Westerly granite is also a quartz monzonite with fine black particles of biotite, medium color and fine even texture. (3) The red Westerly granite is a biotite granite of reddish gray color, speckled with black, and varying from medium to coarse texture. (See Fig. 61.)

South Carolina.—The chief producing granite areas of the state are situated in Edgefield, Fairfield, Lancaster, Lexington, Pickens and Richland Counties. They are essentially

Fig. 61.—Mausoleum of Russell Sage, cut from Westerly, Rhode Island, granite and erected in Oakwood Cemetery, Troy, New York. H. Q. French, architect. By courtesy of E. L. French.

biotite granites and range in color from light to dark gray and in texture from fine to coarsely porphyritic.

Tennessee.—The granites of this state are found in Carter, Cooke, Johnson, Polk and Washington Counties. Some of these are used locally for structural work and some for monumental work.

Texas.— This state produces biotite granites in Burnet County. They are red granites varying in texture from fine to coarse. Also from Gillespie County both red and gray granites. (See Figs. 62 and 63.)

Utah.—The best representative of the Utah granites is found in the Mormon Temple at Salt Lake City. It came from the light gray granite area in Little Cottonwood Canon.

Vermont.—The author has spent some part of twenty-two consecutive summers in detailed work on the Vermont Geological Survey and visited more than one hundred granite quarries, prospects and outcrops, many of which have been briefly described in the Biennial Reports of the State Geologist. It is impossible in this brief work to describe them all. Only the more important areas will· be mentioned. The granites vary widely in color, texture, and in mineral composition. The granite lies between the Connecticut River on

Fig. 62.—Red granite quarry, Granite Mountain, Burnet County, Texas. By courtesy of W. B. Phillips.

the east and the main axis of the Green Mountains on the west. Every county in the eastern half of the state carries granite. The granites were intruded not only into the Waits River limestones and associated phyllite schists of Ordovician age, but also into the Cambrian metamorphics that flank them upon both the east and the west. The intrusives often appear as the upper portions of a great batholith. One peculiar and interesting feature of these granites is the large inclusions of the intruded rocks, sometimes more than fifty feet in diameter. The most of the granites, if not all, were

introduced with the Devonian revolution for they appear in
Canada cutting distinctly Devonian strata. Some of them,
however, may be as late as the Carboniferous, and the asso-
ciated diabase dikes and stocks so pronounced in the northern
part of the state as late as the Triassic. There was, however,
an earlier period of granitic intrusion into the Cambrian
terranes for boulders of granite are found in the Irasburg
conglomerate which forms the base of the Ordovician series.

The granites of Vermont appear in seven of the fourteen
counties of the state, viz: Caledonia, Essex, Orange, Orleans,
Washington, Windham and Windsor. The granite deposits
of the towns in each county will be considered in alphabetic
order, regardless of the commercial significance of the rock.

Fig. 63.—State Capitol, Austin, Texas, built of red granite from
Granite Mountain, Texas. Photo. furnished by D. J. Jones.

Caledonia County

Groton.—The Groton granite is a quartz monzonite which
is quite extensively advertised as the " Vermont blue granite."
In color it is decidedly bluish gray which fact is responsible
for its commercial name. In texture it varies from fine to
medium. The stone takes a good polish and is used largely
for monumental work. (See Fig. 64.)

Hardwick.—The town of Hardwick has furnished three
different grades of granite for monumental work. (1) A fine
light gray granite bearing but little biotite, from which more

than fifty statuettes have been carved. (2) A medium gray to dark quartz monzonite from the Mackville quarries. (3) A quartz monzonite from Buffalo Hill. This stone is named "dark blue Hardwick." It is darker than the highly prized dark Barre granite and lighter than the darkest of the Quincy granite. Its rich color is due in part to the smoky quartz and in part to the presence of much biotite uniformly scattered throughout the stone: perhaps in part also to the paucity of the white mica, or muscovite. The stone receives a fine polish and in texture it is medium.

Fig. 64.—Granite quarry, Groton, Vermont, showing thickness of sheets. Photo. by C. H. Richardson.

Kirby.—The Grout quarries are situated on the south side of Kirby Mountain. The stone is a light to medium biotite granite, of fine even texture, and has been sold under the name of "light Barre granite" which it somewhat closely resembles. The stone is very bright in color. The fine mica crystals throughout the stone, together with the light colored quartz, prevent strong contrasts.

The Burke quarries and the Kearney Hill quarries are situated on the west foot of Kirby Mountain. They both represent quartz monzonites which shade from light to medium gray in color, and from fine to coarse texture. The latter quarries yield the coarser stone of the two products. (See Fig. 65.)

Newark.—The town of Newark is capable of producing a granite that is quite unlike in color any other stone in the state. The stone is a biotite granite shading from a light pink to a red color. It is commercially called " Newark pink granite." It is of rather coarse texture. The stone is susceptible of a good polish and well suited for monumental

Fig. 65.—Granite quarry, Kirby Mountain, Vermont, showing thickness and dip of sheets. Photo. by C. H. Richardson.

or decorative work. The author collected samples from Newark before the quarries were opened and had the samples polished. It appears equal in decorative effect with the kindred granites of Maine and Scotland. (See Fig. 66.)

Ryegate.—The Ryegate quarries are situated on the southwest and northeast slopes of Blue Mountain. The former are quartz monzonites and the latter a biotite granite. They vary in color from light to medium and in texture from fine to medium. They are used for monumental and structural work. (See Fig. 67.)

Essex County

According to C. H. Hitchcock nearly all of this county is underlaid by granite. Some stone has been blasted for foundation work but no quarries have to the present time been systematically worked. Later reconnaissance work has proven the rocks to be metamorphosed sedimentaries with some granitic intrusives.

Orange County

Chelsea.—Where the towns of Chelsea, Strafford, Tunbridge and Vershire meet in a common corner there appears a granite outcrop which has been worked to some extent for monumental purposes. The stone is of a light 'gray color and of medium texture. Distance from railroads is the chief difficulty in its development.
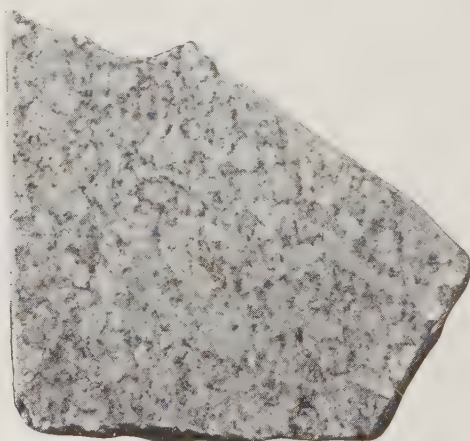
Fig. 66.—Polished sample of red granite, Newark, Vermont. Photo. by C. H. Richardson.

Randolph.—The granite of Randolph is a quartz monzonite. It stands next to the Bethel in whiteness amongst all, the granites of the state. Biotite which characterizes most of the granites of the state is wanting. Muscovite, the white mica, is present only in small proportion, 2.3 per cent. The stone is of fine even texture, hammers white, receives a high polish and is well suited for monumental and structural work.

Topsham.—There are numerous small outcrops of granite in Topsham and some of these have been worked locally for underpinning and monumental purposes. Two localities only

are extensively operated. One of these is near the village of
South Ryegate in Caledonia County and the other is on Pine
Mountain. The granites are quartz monzonites of bluish gray
color and medium texture. (See Fig. 68.)

Williamstown.—The Williamstown granites belong to the
same great mass as the Barre granites in Washington County.

Fig. 67.—Granite quarry, Blue Mountain, Ryegate, Vermont. Photo.
by C. H. Richardson.

They are of dark gray color and of fine to medium texture.
They are sold under the names of " dark Barre " and " dark
blue granite."

Orleans County

Craftsbury.—An orbicular granite occurs in the village of

Craftsbury and immediately to the east of the village. This granite is sufficiently peculiar to merit more than a passing notice. It was described by C. H. Hitchcock and A. D. Hager in their Report on the Geology of Vermont, Vol. II, 1861, as a concretionary granite and as Craftsbury pudding granite. It was also described by G. Hawes in 1878 and by K. Chrus-

Fig. 68.—Polished slab of Waits River granite, Topsham, Vermont. Photo. by C. H. Richardson.

Fig. 69.—Orbicular granite, Craftsbury, Vermont, showing concentric arrangement of orbules. Photo. by C. H. Richardson.

thov in 1878 and 1894. Also by T. N. Dale in Bull. 275, U. S. Geological Survey, 1906. It was photographed and briefly described by C. H. Richardson in the Report of the Vermont State Geologist of 1905-1906 and also in the Report of 1911-1912

by the same author. Orbicular granites are also found in Stanstead, Quebec, and in Bethel, Newfane and Northfield, Vermont, but in these localities the orbicular structure is not so pronouncedly developed. In the Bethel granite the discoid forms lie in sheets parallel to the flow structure of the outer portions of the granite mass, and the major axes of the discs are parallel to the micaceous flowage bands. B. Frosterus applies the principle to the orbicular granites of Finland, and T. N. Dale to those of Bethel, that the nodules are basic segregations lying in a more basic part of the granite, in-

Fig. 70.—Orbicular granite, Craftsbury, Vermont, showing rift and arrangement of orbules. Photo. by C. H. Richardson.

dicating that the orbicular structure is simply a basic flowage and that the nodules themselves lie in this as still more basic segregations. (See Fig. 69.)

The nodules in the Craftsbury granite consist mainly of convex scales of biotite with some quartz granules and feldspathic particles. The convolutions and elongations of the discoid particles suggest the existence of a strain after segregation was complete. They are scattered with a fair degree of uniformity throughout the entire granite stock, differing in-

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in this respect from the other areas cited above. A cubic block of this granite in the museum at Syracuse University shows the nodules to be arranged in a somewhat orbital manner, the outer circles increasing constantly in diameter. This assemblage of black nodules in the gray mass of the granite suggests a basic segregation of the most basic material in a magma more basic than that which represents today the normal biotite granites of the state. The visible outcrop may represent only the peripheral portions of the granite stock and, if so, the nodules themselves lie in the zone of flowage. The quarries have never been opened beneath the surface because the nodules preclude a high polish of the stone, and

Fig. 71.—Granite quarry, Newport, Vermont, showing thickness and curvature of sheets. Photo. by C. H. Richardson.

its use for structural work. It has been used to a considerable extent for cellar walls, underpinnings, abutments of bridges and guards. The stone possesses good rift and grain. (See Fig. 70.)

Derby.—Three different types of granite are quarried in the township. (1) A quartz monzonite bearing both muscovite and biotite. The stone is of bluish gray color and varies from fine to medium texture. The stone grades between the lightest of the Barre granites and those of Hallowell, Maine. This granite is easily worked, and is well suited

for both monumental and constructional purposes. (See Fig. 71.)

(2) The granite near Beebe Plains is a very light gray color and of even medium texture. It is however darker than the Bethel stone. It bears biotite uniformly distributed throughout the stone.

Fig. 72.—Jones Brothers granite quarry, Barre, Vermont, showing excavations over 300 feet in length. Photo. by C. H. Richardson.

(3) The third type is found on the line of the International Boundary between Vermont and Canada. It is only a short distance south of the Graniteville, Quebec, quarries. The stone is in part a very dark stone almost equal to the black granites of Maine. It is rich in biotite and represents a segregation of the more basic product of the main magma.

Irasburg.—At the eastern base of the Lowell Mountain in Irasburg there is a light gray biotite granite of fine and even texture. It possesses perfect rift and grain. Blocks of any dimension desired can be obtained. It takes a good polish and is well suited for structural purposes.

Fig. 73.—A derrick inverted by the removal of the granite too close to a steep wall of mica schist, Barre, Vermont. Photo. by C. H. Richardson.

Washington County

Barre.—The granite industry which has made the city of Barre possible is centered at Websterville and Graniteville about ten miles to the southeast of Montpelier, the Capital of the State. The Harrington quarries were opened in 1837 to provide the stone for the construction of the Capitol build-

ing. The statement was then made that "This is the last structure that will ever be made of Barre granite, and the last load that will ever be drawn from Harrington Hill." The fame of the granite is now world-wide and the annual production from Harrington Hill surpasses $1,000,000. This hill is the present site of Graniteville.

Fig. 74.—Jones Brothers quarry, Barre, Vermont, showing contact of granite with phyllite schist. Photo. by C. H. Richardson.

The Barre granites are known commercially under the following names: "white Barre," "light Barre," "medium Barre," "dark Barre" and "very dark Barre." These names are all based upon the prevailing colors of the quarry products. The Barre granites grade in texture from fine through medium to coarse. They are all true biotite granites with a

paucity of muscovite wherever the white mica is present. The quarries are far too numerous and too much alike to mention in detail. The quarries show a sheeted structure save the Innes and Cruikshank quarry at Websterville which represents a boulder quarry. The granites are monumental, inscriptional, decorative and constructional. It is doubtful if

Fig. 75.—Wetmore and Morse granite quarry, Barre, Vermont, showing sheeted structure. Photo. by C. H. Richardson.

any granite in America is more widely known than the Barre granite. (See Figs. 72, 73, 74, 75, 76, 77, 78 and 79.)

Cabot.—The granite of Cabot is a quartz monzonite of dark bluish gray color, as dark as the darkest of the Barre granites. It is of fine even structure and takes a good polish. The clear quartz and black mica give the stone a strong mineral contrast.

Calais.—The granites of Calais are biotite granites of light to medium gray color and of fine to medium texture. The product is used largely for monumental work. (See Fig. 80.)

Woodbury.—The granites of Woodbury where quarried, with the exception of that of Nichols Ledge, are either on Robeson Mountain or in its immediate vicinity. They occupy

Fig. 76.—Wetmore and Morse granite quarry, Barre, Vermont, showing head seam back of which there is much good granite. Photo. by C. H. Richardson.

a somewhat irregular area with a diameter of about four miles. Granite masses however appear upon the west side of the valley that separates Robeson Mountain from Woodbury Mountain but these are not quarried to any considerable extent. The Woodbury granites proper are all biotite gran-

ites. They shade in color from white, or light cream color, through medium gray to a dark gray. They possess even medium texture.

The Fletcher quarries are on the southeast and southwest sides of Robeson Mountain. One set of sheets varies from one to five feet in thickness and another set varies from five to nine feet in thickness. T. Nelson Dale states in the Report of the Vermont State Geologist, 1909-1910, " In 300 granite quarries visited thus far by the writer this is the first case of double-sheet structure or horizontal jointing observed." Dale explains this peculiarity by the existence at some time of a

Fig. 77.—Entrance to postoffice, Barre, Vermont, built of light gray Barre granite. Photo. by C. H. Richardson.

secondary compressive strain operating differently from that which produced the primary sheet structure to which Robeson Mountain owes its form. (See Figs. 81 and 82.)

The late George H. Bickford, President of the Woodbury Granite Company, classified their granites as " Vermont white," " Imperial blue," and " Woodbury gray." The Woodbury white granite is a very light, slightly buff or cream-tinted stone. Its quartz is of pale hue and there is a paucity of the black mica, biotite. This gives the stone a strong mineral contrast.

The Woodbury gray and the Woodbury fine dark gray granites are on the east to northeast sides of Robeson Mountain and are of fine even texture. The sheets sometimes reach a thickness of forty feet. It is doubtful if larger blocks can be quarried from any stone in America than can be obtained at these quarries, or that any company has facilities for handling larger blocks than the Woodbury Granite Company. The Imperial blue quarries are located near Buck Lake and

Fig. 78.—Monument cut from Barre granite and erected in the cemetery at Hardwick, Vermont. Photo. by C. H. Richardson.

are called the Buck Lake quarries. The stone is of dark bluish gray color and of fine even texture. The Carnegie library, Syracuse, N. Y., contains the Woodbury gray granite.

The Nichols ledge granite is from light to bluish gray color and of very fine texture. Distance from the railroad militates against a large development of these quarries. (See Figs. 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93 and 94.)

Windham County

Dummerston. — The commercial granites of Windham County are situated on the northeast, south and southwest sides of Black Mountain. They are all quartz monzonites. The West Dummerston white granite bears both muscovite and biotite and is of medium texture. The product is used for monumental work, structural and paving blocks. The quarries on the south and northwest sides of Black Mountain produce granites of darker hue and finer texture than those on the southwest side of the mountain. (See Fig. 95.)
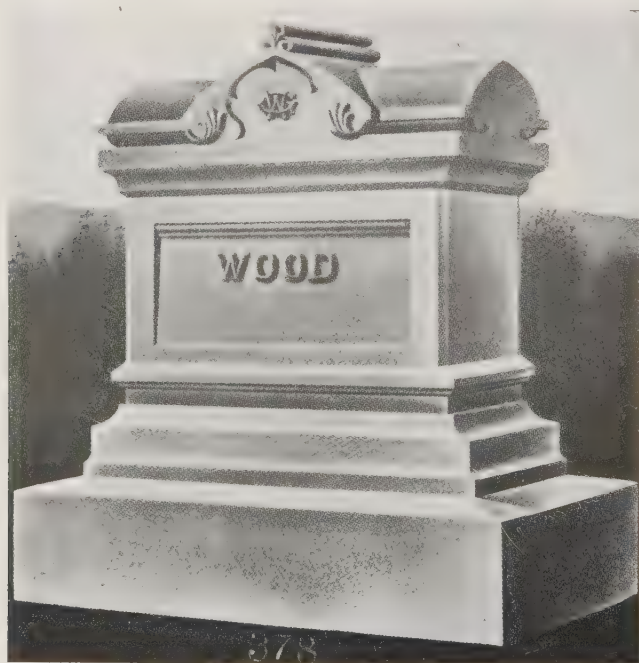
Fig. 79.—Monument cut by Redmond and Hartigan from Barre granite, Barre, Vermont. By courtesy of Redmond and Hartigan.

Windsor County

Bethel.—The Bethel granite is situated on Christian Hill about three miles north of the village of Bethel. The quarries of the Ellis Brothers are on the east side of the hill and those of the Woodbury Granite Company on the east side and top of the hill. The granite is a quartz monzonite, in texture varying from fine to coarse. It surpasses all other

known granites in its peculiar whiteness. The author has compared freshly dressed blocks of this stone with the interior of a building painted with white lead and found the granite the whiter of the two. Its whiteness is due to the presence of clear colorless quartz, white oligoclase, clear orthoclase, white muscovite and a paucity of the black mica, biotite. Many of the polished discs appear to contain no visible biotite. The granite is hard, cuts to a perfect edge and is one of the best constructional stones in America. It occurs in sheets varying in thickness from five to twelve

Fig. 80.—The Patch Company granite quarry, Calais, Vermont, showing thickness and steep dip of sheets. Photo. by C. H. Richardson. .

feet. The stone has a remarkable compression test. As determined by the United States Arsenal at Watertown, Mass., it is 33,153 lb. to the cubic inch. (See Figs. 96, 97, 98, 99 and 100.)

Windsor.—The granites quarried in Windsor are situated on the north and west sides of Mount Ascutney. The altitude of the mountain as given by the average of 21 different observations made by the author is 3,320 feet. It rises more

than 3,000 feet above the Connecticut River, and 2,999 feet above Windsor. The granite mass was intruded into the limestones and slates of Ordovician age. The present, isolated,
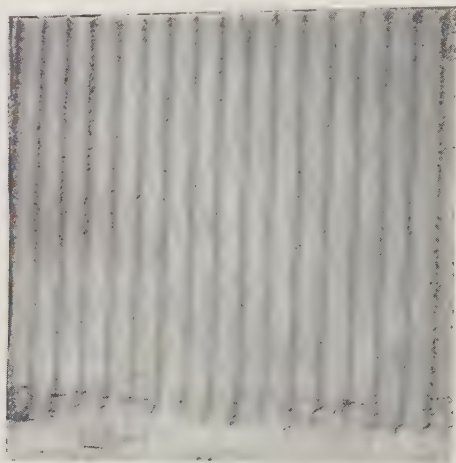
Fig. 81.—A 6-foot sheet of granite in the E. R. Fletcher quarry, Woodbury, Vermont, showing the work of the channelling machine. Photo. by C. H. Richardson.
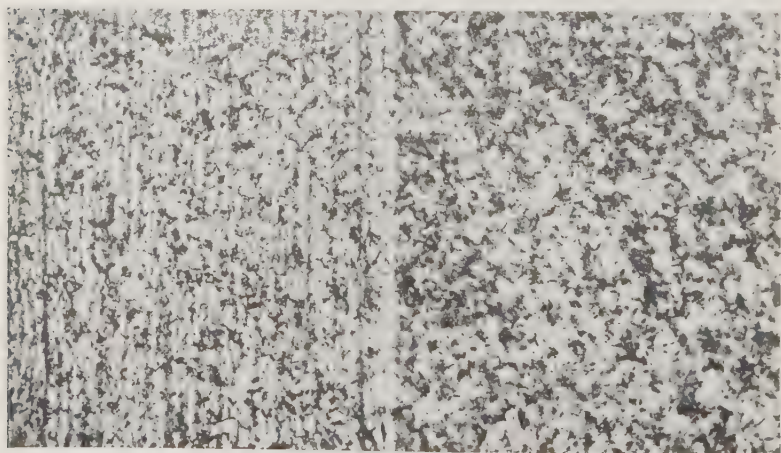
Fig. 82.—E. R. Fletcher granite, Woodbury, Vermont, showing polished and hammered surface. By courtesy of E. R. Fletcher.

conical peak, Mount Ascutney, may be taken as a measuring rod of the amount of denudation that has taken place in

Vermont since the intrusion of the various granites. With this mountain as a measuring rod the amount of erosion could not have been less than 3,000 feet. It probably was considerably greater than the above figure. The granite of Ascutney has been described by R. A. Daly, Bulletin 209, U. S. Geological Survey, 1903. Daly classifies the stone as a nordmarkite. It was earlier classified by C. H. Hitchcock as a

Fig. 83.—Quarry of the Woodbury Granite Company on Robeson Mountain, Woodbury, Vermont, showing thickness of granite sheets. Photo. by C. H. Richardson.

syenite. It is a hornblende-augite granite. Its mineral composition as given by T. Nelson Dale in descending order is dark olive green orthoclase, interwoven with oligoclase with cleavage planes stained with limonite; dark smoky

quartz with cracks stained with limonite; green hornblende; augite; biotite present in only one of the four slides examined. The accessory minerals are titanite, magnetite, or ilmenite, zircon, apatite and allanite. The secondary minerals are limonite and a white mica.

The stone changes from a dark bluish gray color when freshly quarried to a green color upon exposure to the atmosphere. This change of color is due to the oxidation of extremely minute blackish granules of ferrous oxide in the feldspars, and to the combination of yellowish brown color from the limonite thus produced with the bluish gray color of the unaltered feldspars. A part of this limonite is undoubtedly due to the oxidation of the iron content of the accessory allanite.

Fig. 84.—Polished disc of Woodbury gray granite from quarry shown in Fig. 83. Photo. by C. H. Richardson.

This granite is best suited for dies, monumental, inscriptional, wainscoting and columnar work. In the absence of the common micas the stone takes a very high polish and the polished surface of the raised letters stands out in striking contrast with the hammered surfaces. The sixteen polished columns of the Library of Columbia University, New York, are of this stone. (See Fig. 101.)

Virginia.—The granites of Virginia are found chiefly in three districts, Fredericksburg, Petersburg and Richmond areas. The first area furnishes a muscovite granite that is

very light gray in color and of medium texture; also a biotite
granite of dark bluish gray color and fine texture. The second
area produces a biotite granite of light to dark gray color
and of fine and medium texture; also an exceptionally beau-
tiful porphyritic granite from near Midlothian. The third
area furnishes a biotite granite of gray color and medium
texture.

Fig. 85.—Granite quarry of the Woodbury Granite Company, near
north end of Robeson Mountain, Woodbury, Vermont, showing thick-
ness and dip of sheets. Photo. by C. H. Richardson.

Wisconsin. — According to T. C. Chamberlin the great
Laurentian area of the northern portion of Wisconsin is
covered with granites and gneisses. Quarries are operated
in Marathon and Marquette Counties and furnish fine granites
of pink color and even texture.

Wyoming.—Near the highest point of the Northern Pacific Railroad at Sherman there is a large body of coarse red granite that is quite similar to the Scotch granite, so largely imported into this country for monumental work.

FOREIGN GRANITES

British Columbia.—Granites are quarried on Jarvis Inlet and Burrard Inlet and the product is largely consumed in the vicinity of Vancouver.

New Brunswick.—In Kings County there is a red hornblende granite that is brought into the New England States for monumental purposes under the name of "Bay of Fundy granite." It can be easily distinguished from the red granites

Fig. 86.—Polished slab of Vermont white granite, Robeson Mountain, Woodbury, Vermont. Photo. by C. H. Richardson.

of New England because its ferromagnesian mineral is hornblende instead of biotite or muscovite. It is susceptible of a high polish on account of the absence of the highly cleavable micas.

Nova Scotia.—Gray biotite granites are quarried at Shelburne and Purcell's Cove in Halifax County and imported to some extent into the United States. These vary in texture from fine to coarse.

Ontario.—One of the best granites of Ontario is that found at Kingston. It is a red granite of fine and even texture well suited for monumental and decorative interior work.

Quebec.—Quartz monzonites, biotite granites and hornblende granites are extremely abundant in the Province of Quebec. The author has visited scores of fine quarries in

this Province. They duplicate the Vermont product in all respects save the white granite of Bethel and the green granite of Mount Ascutney.

England.—The most important granitic intrusions in England which yield stone for structural purposes are located in

Fig. 87.—Imperial blue granite quarry, Buck Lake district, Woodbury, Vermont, showing head seams. Photo. by C. H. Richardson.

Cornwall and Devonshire. According to J. Watson this belt extends in the form of a broken chain from Dartmoor to the Scilly Islands. The stone has been quarried for many centuries. The ancient cromlechs, monoliths, Celtic crosses and

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hut dwellings scattered over England were made of granite. The granites are mostly muscovite-biotite granites varying in color from light to dark gray and in texture from fine to coarse. Where porphyritic the phenocrysts of feldspar are called by the quarrymen " Horses' Teeth." (See Fig. 102.)

Ireland.—The principal granite producing counties of Ireland are Dublin, Wicklow and Wexford. The Dakley quarries are said to have been opened in 1680 and regularly worked ever since. Many of the granites are gray muscovite-biotite irruptives. In some cases the prevailing feldspar, orthoclase, is a delicate pink. Such stones are susceptible of a high polish and largely sought for decorative work.

Scotland.—According to J. Watson granite was quarried in Scotland as early as 1764 and used for paving the streets of London. The granites quarried in the Aberdeen district
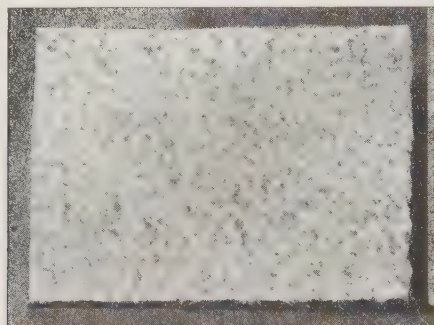
Fig. 88.—Polished slab of Imperial blue granite, Woodbury, Vermont. Photo. by C. H. Richardson.

and immediate vicinity range from fine to medium in texture, and in color from a light silvery gray, blue gray, dark gray to red. The Peterhead granite falls into two types. One is of blue color and the other is red. They grade from medium to coarse in texture. The red Peterhead has been introduced in nearly all the countries of the world as a decorative stone of great beauty. Its mineral composition is quartz, orthoclase, albite and biotite. The Aberdeen stone bears oligoclase in the place of albite. (See Figs. 103 and 104.)

Egypt.—The term syenite came from the town of Syene, Egypt, where the irruptive granitic rocks of the country were quarried about 1300 years before the beginning of the Christian era and fashioned into colossal statues, obelisks and sarcophagi. The true syenite of today is a plutonic rock con-

Fig. 89.—Memorial Hall, Hardwick, Vermont, built of Woodbury gray granite.   Photo. by C. H. Richardson

sisting of orthoclase and hornblende. The Egyptian syenite is a granite whose mineral composition is quartz, orthoclase, (and a whitish feldspar), biotite and hornblende. The obelisk in Central Park, New York City, came from Syene, Egypt. All of its hieroglyphics have had to be recut because the stone disintegrates rapidly in America, although permanent under Egyptian skies.

Sweden.—The Swedish rose granite from the Graversfors district has dark red orthoclase with deep blue and purple quartz. (See Fig. 105.)
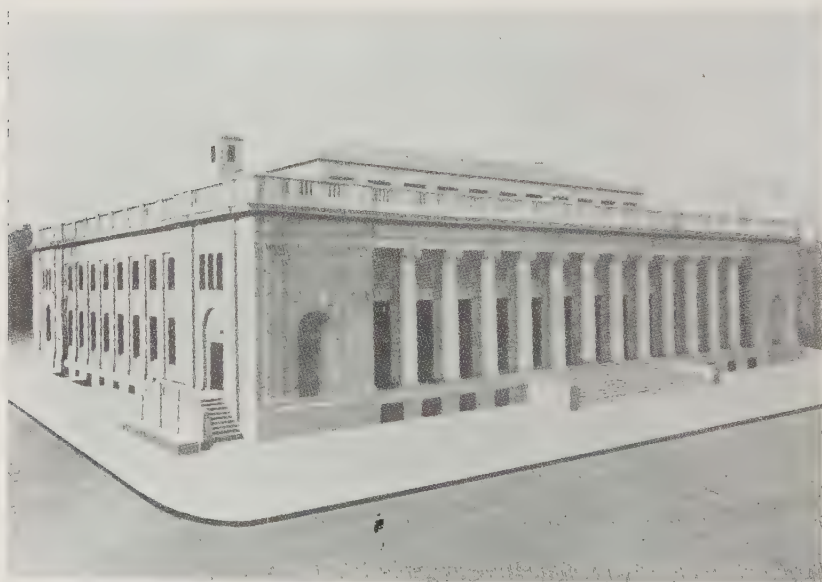
Fig. 90.—Post Office, New Bedford, Massachusetts, built of Wood-bury gray granite from Woodbury, Vermont. By courtesy of G. H. Bickford.

Practically all countries of the world are producers of granite in some quantity. Many of these granites are highly decorative stones while others are better suited for constructional purposes.

INDUSTRIAL FACTS ABOUT GRANITE

Uses.—The use to which a granite will be put depends upon its color, texture, hardness, compressive test, tensile strength, susceptibility of polish, and in part to its mineral-

Fig. 91.—Pennsylvania State Capitol, Harrisburg, Pennsylvania, built of Woodbury gray granite. By courtesy of the Woodbury Granite Company.
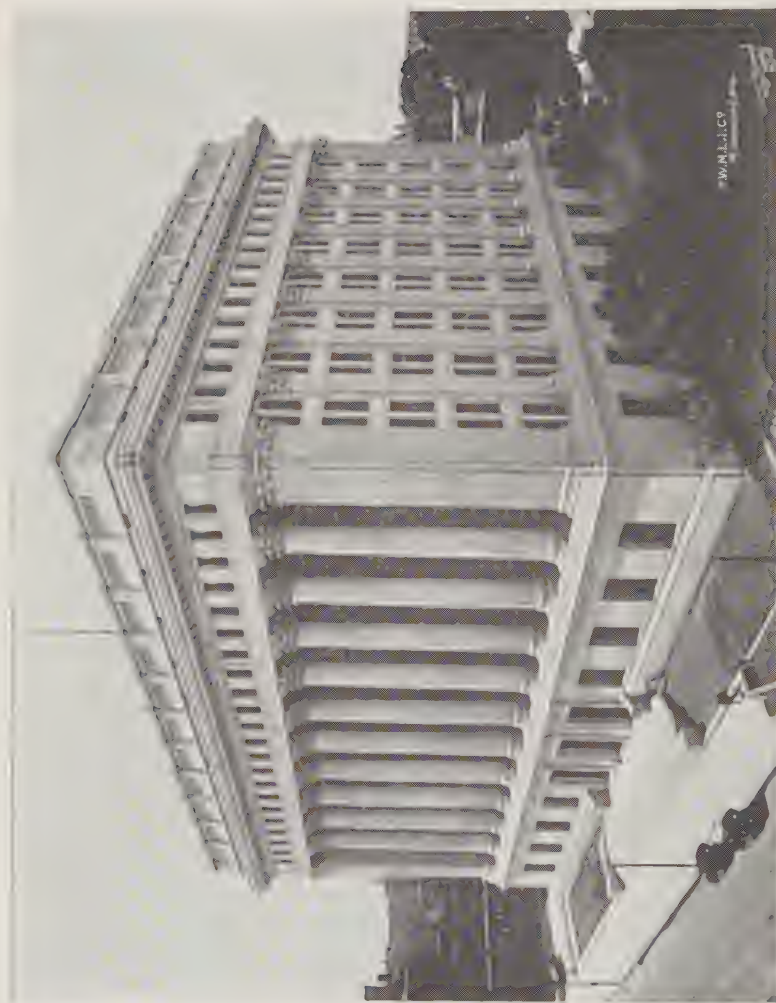
Fig. 22.—Northwestern Mutual Life Insurance Building, Milwaukee, Wisconsin; built of Vermont white granite from Woodbury, Vermont. By courtesy of the Woodbury Granite Company.

Fig. 93.—Soldiers' and Sailors' Memorial, Wichita, Kansas, built of Vermont white granite. By courtesy of the Woodbury Granite Company.

Fig. 94.—Post Office, Providence, Rhode Island, built of Woodbury gray granite. Photo. by Wm. Mills and Son, Providence, Rhode Island.
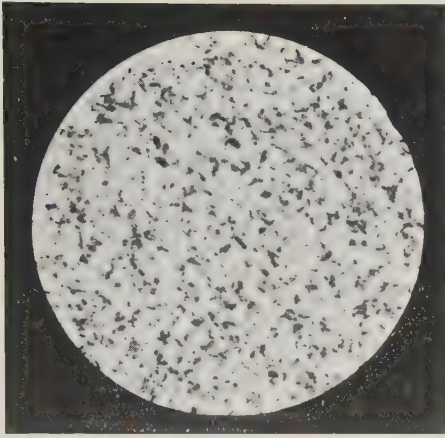
Fig. 95.—Polished disc of white granite, West Dummerston, Vermont, from quarries of W. N. Flynt Granite Company. Photo. by C. H. Richardson.

Fig. 96.—Granite quarry, Bethel, Vermont, showing sheeted structure. Photo. by C. H. Richardson.

Fig. 97.—West front of State Capitol, Madison, Wisconsin, built of Bethel white granite. By courtesy of the Woodbury Granite Company.

Fig. 98.—East pediment of Wisconsin State Capitol, Madison, Wisconsin, built of Bethel White Granite. C. A. Weinman, sculptor. By courtesy of the Woodbury Granite Company.

Fig. 99.—Building of Union Trust Company, Rochester, New York, built of Bethel white granite. By courtesy of the Woodbury Granite Company.
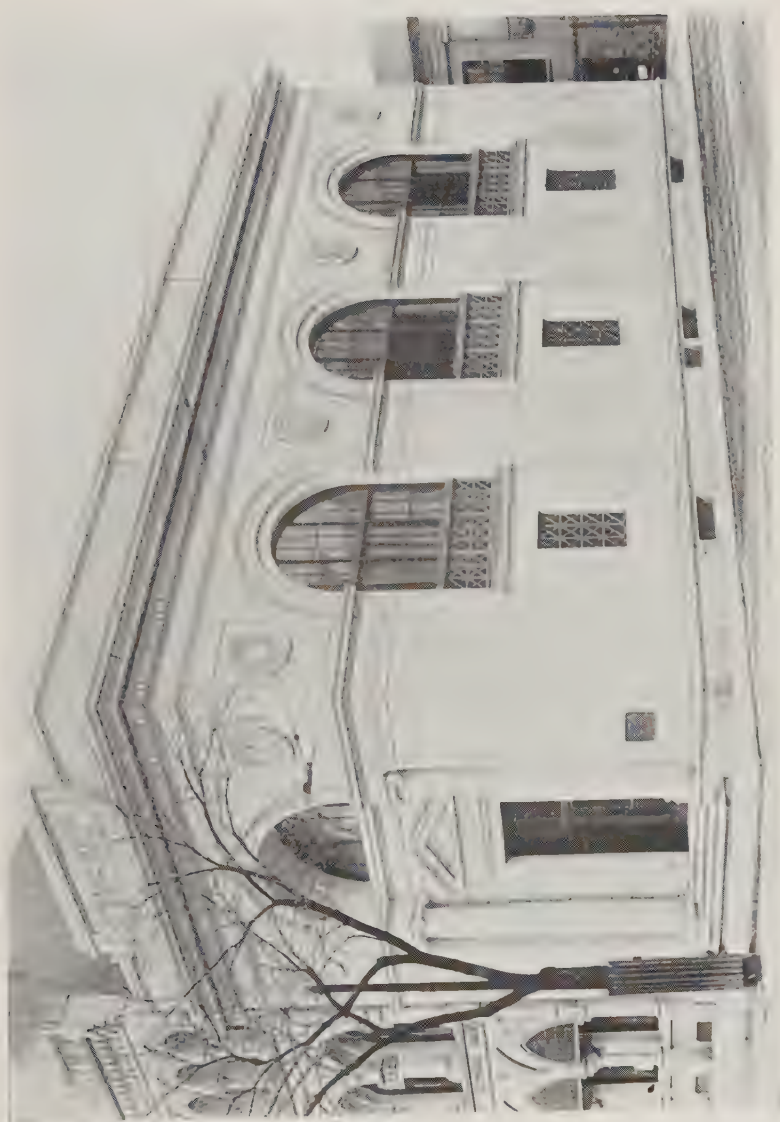
Fig. 100.—Franklin Savings Bank, Greenfield, Massachusetts, built of Bethel white granite. Photo. by T. C. Hopkins
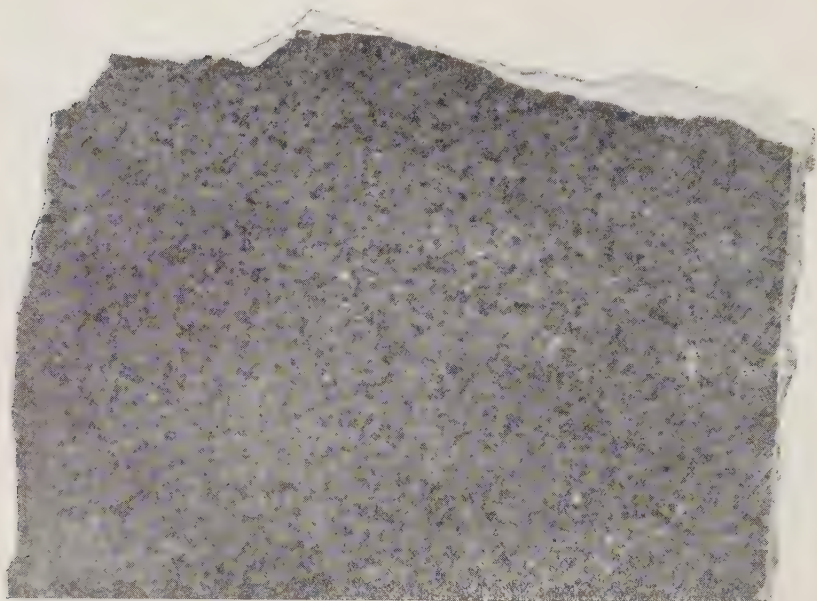
Fig. 101.—Polished slab of nordmarkite from the northeast side of Mount Ascutney, Windsor, Vermont.   Photo. by C. H. Richardson.
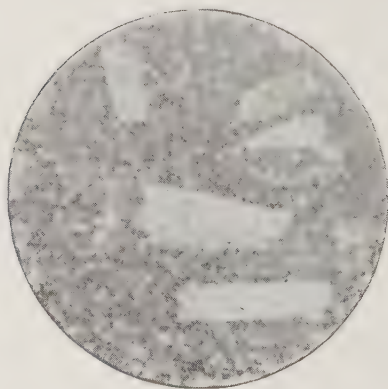
Fig. 102.—Polished disc of porphyritic granite showing "Horses Teeth."   Photo. by C. H. Richardson.
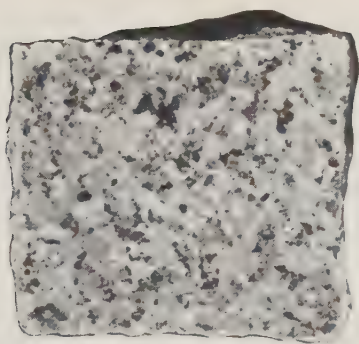
Fig. 103.—Polished slab of Scotch granite, Peterhead, Scotland. Photo. by C. H. Richardson.

Fig. 104.—Monument of Scotch granite in Green Mountain Cemetery, Montpelier, Vermont, erected in 1882. Photo. by C. H. Richardson.

ogical composition. The white and light gray granites are especially desirable for constructional purposes. The dark gray, pink and red granites are used more largely for monumental, inscriptional stone and for decorative interior work. Granites like that of Quincy, Mass., have been extensively used in this line of work, as well as the red granite of Peterhead, Scotland. Granite is also used for trimming, curbing, paving, etc. It is often crushed and used for permanent road material. But the basic irruptives have better cementing

Fig. 105.—Monument of Swedish granite set in the Catholic cemetery, Montpelier, Vermont. Photo. by C. H. Richardson.

qualities and their feldspars are equally resistant to abrasion. Therefore they make the better road metal. Granites are also used for ballast, riprap and rubble.

Quarrying.—The object in quarrying granite is to secure symmetrical rectangular blocks with the least possible waste of material, time and money. Advantage is taken of the sheeted structure of quarries whenever that structure is

Fig. 106.—Channelling machine at work on Wetmore and Morse quarry, Barre, Vermont. Photo. by C. H. Richardson.

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of a marked character. The quarry is opened in such a manner that the quarry floor slopes away from the working face. In many quarries no blasting powder, rend rock, dualline, dynamite or nitroglycerine is used. Where the sheets are much thicker than can be split with wedges, Lewis holes or Knox holes are drilled at varied intervals to depths depending upon the thickness of the block desired and then fired simultaneously. The blocks are afterward split with wedges into smaller dimensions. Explosives often develop fracture planes that are not visible until the stone is polished or dressed. They are planes of weakness. They also make possible a more rapid disintegration of the finished product.
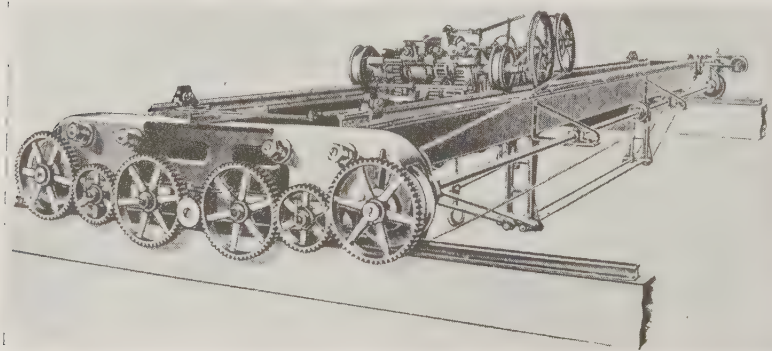
Fig. 107.—Rope-driven traveling crane made by the Lane Manufacturing Company, Barre, Vermont. By Courtesy of the Lane Manufacturing Company.

Polishing Granite.—The most expensive finish for granite is the polish. The process brings out the grain and mottle of the stone in its full beauty. The process of polishing granite is slow and costly, but the finished product is handsome, durable and easily cleaned. The rough block is first ground by heavy iron scrolls to an even surface. After thorough washing the stone is rubbed with carborundum which further smooths the surface. The stone is again washed and putty powder is applied and rubbed into the surface with heavy felt buffers. It is this final process which gives the gloss and closes the surface to a uniform finish.

Good granite when properly polished will hold its gloss for fifty years or more in spite of exposure to the corrosive

FIG. 108.—30-ton electric crane for handling granite, Woodbury Granite Company, Hardwick, Vermont. By courtesy of G. H. Bickford.

agents of the atmosphere. If oxalic acid is used in the process
of buffing in the place of putty powder the life of the stone
is short. (See Figs. 106, 107, 108, 109, 110, 111, 112, 113, 114,
115, 116 and 117.)

Fig. 109.—Carborundum saw at work in granite in the sheds of the
Woodbury Granite Company, Hardwick, Vermont. Photo. by C. H.
Richardson.

Compression Tests.—A few compression tests are given as
a matter of reference.

Bay of Fundy	11,916 lb. to the cubic inch
Platte Canon, Colo.	14,634 lb.
Westerly, R. I.	17,500 lb.
Quincy, Mass.	17,750 lb.
Vinalhaven, Me.	18,000 lb.
Barre, Vt.	19,000 lb.
Richmond, Va.	19,104 lb.
Rockport, Mass.	19,750 lb.
Milford, Conn	22,610 lb.
East St. Cloud, Minn	28,000 lb.
Bethel, Vt.	33,153 lb.

Chemical Analyses.—A few analyses of granites are appended here as a matter of reference.

1. Granite from the quarry at North Jay, Maine. Analysis made by Prof. J. E. Wolff of Harvard University, Cambridge, Mass.

SiO_2, silica	71.54
TiO_2, titanium dioxide	0.84
Al_2O_3, alumina	14.24
Fe_2O_3, ferric oxide	0.74
FeO, ferrous oxide	1.18
CaO, lime	0.98
MgO, magnesia	0.34
Na_2O, soda	3.39
K_2O, potash	1.73
H_2O, water	0.61
S, sulphur	Trace
CO_2, carbon dioxide	Trace

98.59

2. Granite from High Isle quarry, Knox County, Maine. Analysis made by Prof. J. F. Kemp, Columbia University, New York City.

SiO_2, silica	74.54
Al_2O_3, alumina	13.30
Fe_2O_3, ferric oxide	0.92
FeO, ferrous oxide	0.79
CaO, lime	1.26
MgO, magnesia	0.009
MnO, manganous oxide	0.51
Na_2O, soda	3.69
K_2O, potash	5.01
S, sulphur	0.038

100.067

3. Granite from Concord, N. H. Analysis made by Prof. W. O. Crosby, Massachusetts Institute of Technology, Boston, Mass.

SiO_2, silica	71.17
Al_2O_3, alumina	14.15
Fe_2O_3, ferric oxide	1.16
FeO, ferrous oxide	1.21
CaO, lime	1.70
MgO, magnesia	0.63
Na_2O, soda	1.97
K_2O, potash	4.14
H_2O, water	0.06
H_2O, water combined	0.20
S, sulphur	0.27
CO_2, carbon dioxide	0.25
	100.21

4. Granite from Bethel, Vermont. Analysis made by C. F. McKenna of New York City.

SiO_2, silica	77.52
Al_2O_3, alumina	16.78
FeO, ferrous oxide	0.84
CaO, lime	2.56
MgO, magnesia	0.32
Na_2O, soda	1.21
K_2O, potash	0.62
Loss on ignition	0.33
	100.18

5. Granite from the Wells-Lamson " dark Barre " quarries, Barre, Vermont. Analysis made by William C. Day at Swarthmore College, Pennsylvania.

SiO_2, silica	69.56
Al_2O_3, alumina	15.38
Fe_2O_3, ferric oxide	2.65
CaO, lime	1.76
MgO, magnesia	Trace
MnO, manganous oxide	Trace
Na_2O, soda	5.38
K_2O, potash	4.31
Loss on ignition, CO_2 and moisture	1.02
	100.06

6. Granite from the Hardwick quarry, Quincy, Mass. Analysis made by H. S. Washington, Washington, D. C.

SiO_2, silica	73.93
TiO_2, titania	0.18
Al_2O_3, alumina	12.29
Fe_2O_3, ferric oxide	2.91
FeO, ferrous oxide	1.55
MnO, manganous oxide	Trace
CaO, lime	0.31
MgO, magnesia	0.04
Na_2O, soda	4.66
K_2O, potash	4.63
H_2O, water above 110° C	0.41

100.91

7. Granite from Milford, Massachusetts. Analysis made by Prof. L. P. Kinnicut, Worcester Polytechnic Institute, Worcester, Mass.

SiO_2, silica	77.08
Al_2O_3, alumina	12.54
FeO, ferrous oxide	0.95
CaO, lime	0.75
MgO, magnesia	0.01
Na_2O, soda	3.64
K_2O, potash	4.99

99.96

8. White granite from W. N. Flynt Granite Company's quarry, West Dummerston, Vermont.

SiO_2, silica	72.80
FeO, oxide of iron	Trace
Al_2O_3, alumina	19.40
CaO, lime	1.00
Na_2O, soda	4.17
K_2O, potash	2.63

100.00

ROCKS RELATED TO GRANITES AND IN PART INCLUDED IN THE ABOVE DESCRIPTION

Aplite.—Aplite is a fine grained aggregation of quartz and feldspar, with a little muscovite, often occurring in dikes. When a granite bears but few phenocrysts of the ferromagnesian minerals it is called aplitic. The contrast in color between the quartz and feldspars is not strong.
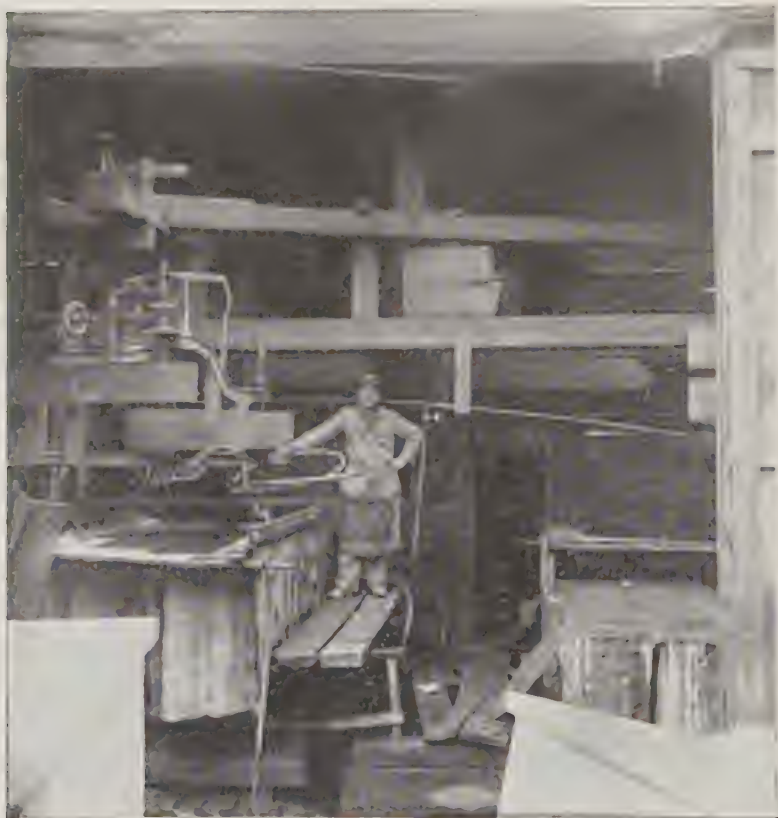
Fig. 110.—Polishing wheel at work, Hardwick, Vermont. Photo. by Smart.

Monzonite.—The monzonites have both the monoclinic feldspar, orthoclase, and the triclinic lime-soda feldspar, or plagioclase, in approximately equal amounts. The quartz monzonites are granites in which the plagioclase equals or exceeds the orthoclase.

Syenite.—This rock is intermediate between a true granite and a diabase. Its mineralogical composition is orthoclase and hornblende. If the micas displace the hornblende the rock is called a mica syenite. The stone is often susceptible of a high polish and commercially used under the name of granite.

Fig. 111.—Gang of 5 saws cutting a block of granite, Hardwick, Vermont. Photo. by C. H. Richardson.

Porphyry.—This term is not to be confused with the porphyritic granites where phenocrysts of feldspar appear more than .4 inch in diameter. The term as there used applies only to texture. The term porphyry as here used embraces two types of acidic intrusives in which some mineral constituent is porphyritically developed in a ground mass that is not in-
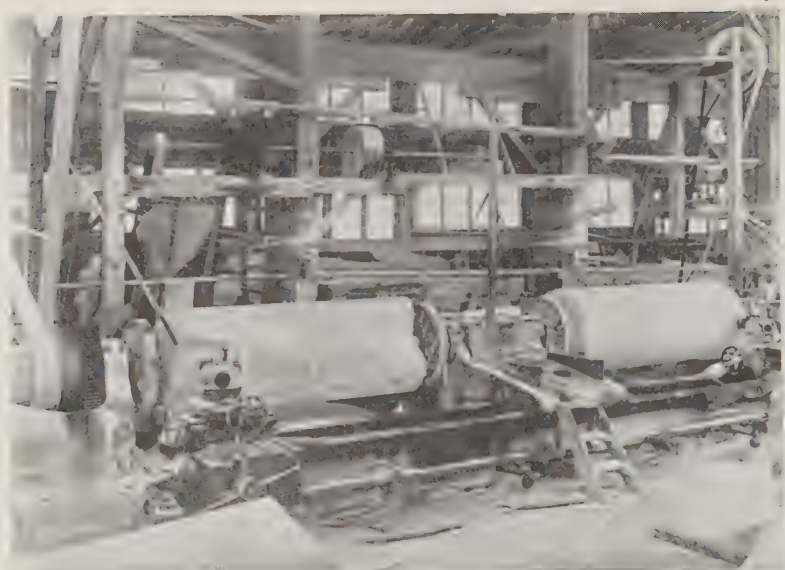
Fig. 112.—Granite lathe working on 2 pieces of granite at the same time. By courtesy of G. H. Bickford.

Fig. 113.—Pirie tool sharpening machine, showing belt conveyor, forge and piles of tools. Photo. by C. H. Richardson.
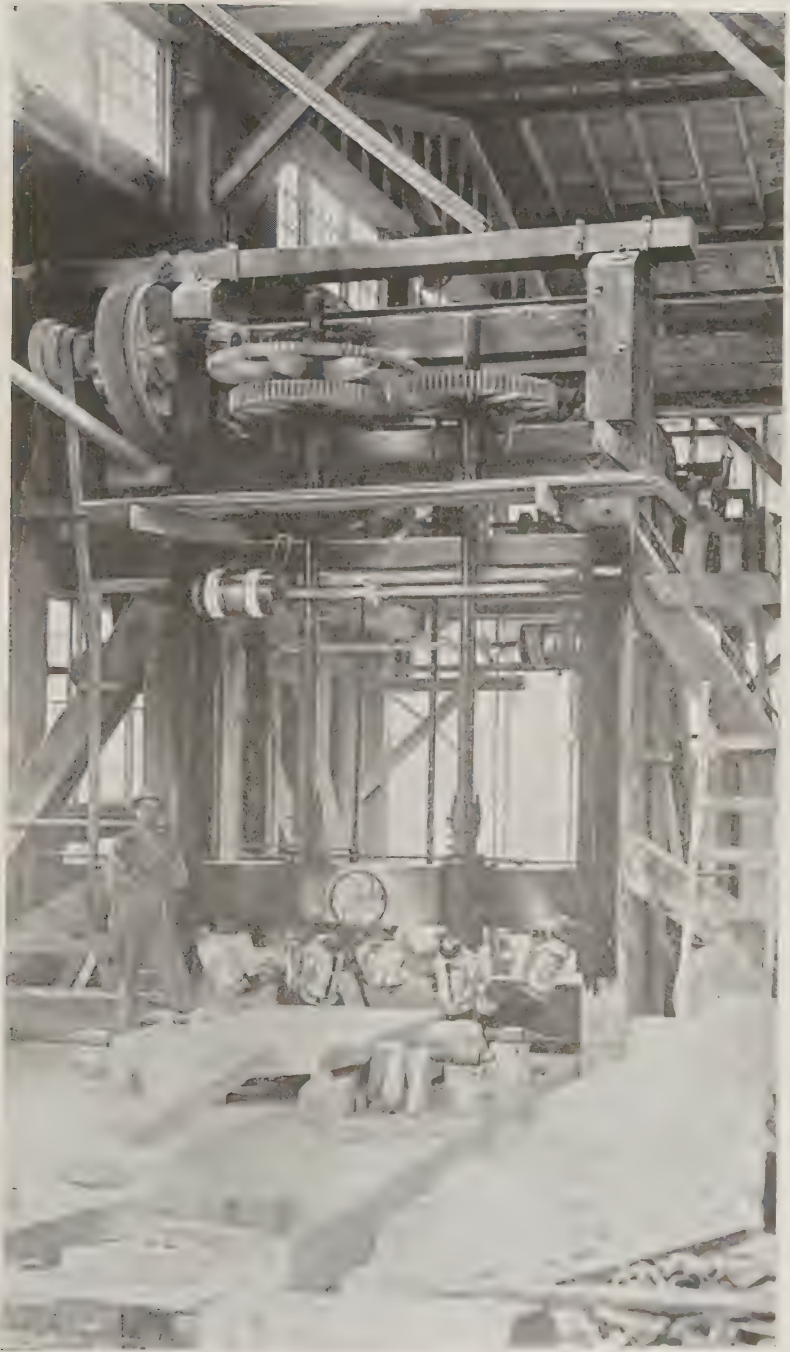
Fig. 114.—McDonald surfacing machine in sheds at Hardwick, Vermont. By courtesy of G. H. Bickford.

dividualized. It requires a petrographic examination to ascertain the mineral content of the glassy ground mass. Quartz porphyries bear phenocrysts of quartz, or quartz and orthoclase, in a glassy ground mass. In an orthoclase porphyry

Fig. 115.—Interior of the big shed of the Woodbury Granite Company at Bethel, Vermont. Photo. by C. H. Richardson.

Fig. 116.—Tripple granite shed of the Woodbury Granite Company at Bethel, Vermont. Photo. by C. H. Richardson.

the phenocrysts are orthoclase and quartz is absent. The porphyries possess a kindred variation in color with the granites shading even to black. Unlike the granites they are

Fig. 117.—Method of chaining a large block of Bethel white granite. By courtesy of the Woodbury Granite Company.

Fig. 118.—Hand polished slab of porphyry, Saugus, Massachusetts. Photo. by C. H. Richardson.

without rift and grain. Many of them take a high polish and some of them are used with good results as decorative material. (See Fig. 118.)

Liparite.—The liparites are extrusive rocks rather than intrusive like the granites. Their essential mineralogical composition is quartz and sanidine. Sanidine is a glassy variety of orthoclase. The liparites grade in texture from the clear glassy forms on the one hand to holocrystalline porphyritic forms on the other. They are not widely used.

Rhyolite.—Rhyolite is the eruptive equivalent of granite and has the same chemical composition. It commonly contains more or less of undifferentiated glass. Obsidian is the wholly vitreous variety. These rocks occur in large masses in many of the western states, and in Colorado they are used for structural purposes.
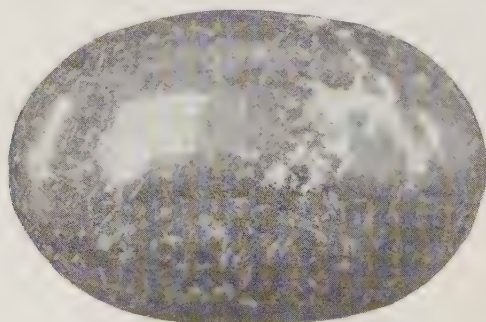
Fig. 119.—Polished boulder of porphyritic diorite, Washington, Vermont. Photo. by C. H. Richardson.

Trachyte.—Trachyte is the eruptive equivalent of syenite. Like a syenite when it bears mica instead of hornblende it is called a mica trachyte. Trachytes are of small significance as structural material. Between the trachytes and the syenites there are intermediate forms analogous to the quartz porphyries.

Phonolite.—This rock receives its name from the fact that it rings clearly when struck with a hammer. Its chief difference from trachyte is that it bears either nephelite or leucite in its mineral composition.

Andesite.—This is a basic eruptive. It is marked by the presence of plagioclase rather than orthoclase. Its ground mass is felsitic. If quartz is present in any appreciable quantity the stone is called a quartz andesite. The varieties

depending upon the prevailing ferromagnesian mineral present are hornblende andesite, augite andesite, hypersthene andesite, mica andesite. These varieties are used somewhat for structural purposes.

Diabase.—This rock is often quarried and sold under the name of "black granite." It is a basic intrusive whose essential mineralogical composition is plagioclase and augite. Olivine is often present, in which case the rock takes the name, olivine diabase. The diabases are massive microcrystalline rocks, without the rift and grain characteristic of granites. They are, however, quarried to some extent and used for decorative interior work. They are susceptible of a high

Fig. 120.—Smoothed slab of orbicular diorite, Dehesa, San Diego County, California. Photo. by C. H. Richardson.

polish, and the polished face receives a lettering legible to a greater distance than many of the granites. The diabases, however, are best suited for the construction of permanent roads, for they have the requisite resistance to abrasion and the desired cementing qualities. (See Fig. 11.)

Basalt.—The term basalt was formerly used for the dark basic volcanic rocks of Tertiary or post-Tertiary age. The time distinction is obsolete. In addition to the necessary

plagioclase and augite, basalts almost always bear olivine as an essential component. The rather rare olivine-free basalt marks a transition to the augite andesites. The basalts lack the characteristic rift and grain of granites, but they are extensively used in the construction of permanent roads.

Diorite.—The diorites are basic irruptives, macrocrystalline, whose essential constituents are plagioclase and hornblende. Phenocrysts of the prevailing feldspar often appear, when the stone is called a porphyritic diorite. These rocks, like the diabases, are without the rift and grain of the granites. They

Fig. 121.—Boulder of gneiss from near Arapahoe Peak, Colorado. Photo. by T. C. Hopkins.

make most excellent road metal for the same reason as the diabase. They receive a high polish and were it not for the question of expense in working would be a valuable decorative stone. (See Figs. 119 and 120.)

Gabbro.—This term was long used for a basic igneous rock whose prevailing ferromagnesian mineral was the bladed or flattened pyroxene, diallage. The term is now largely reserved for field use. Gabbros occur in large masses in the Adirondack region. The hypersthene gabbro whose prevailing feld-

spar is labradorite is a norite which is quite extensively quarried near Keeseville, N. Y., and sold as Keeseville granite. Diabases, diorites and gabbros all appear in the marts of trade under the name of black granites.

Norite.—The norites belong to the gabbro family, their essential minerals are plagioclase, usually laboradorite, and some orthorhombic pyroxene, usually hypersthene. Small quantities of biotite and hornblende may be present. Varieties bearing olivine are also known. The norite of Keeseville, N. Y., is susceptible of a high polish.
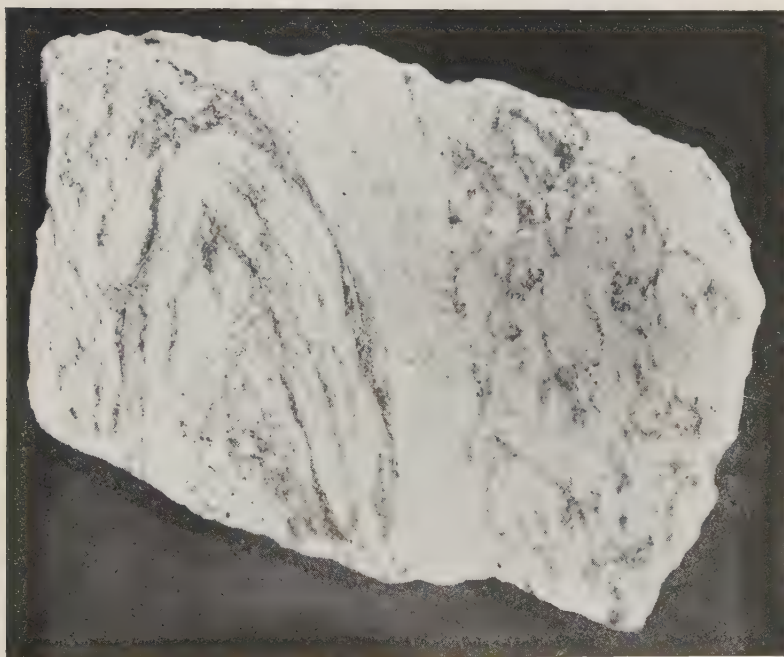
Fig. 122.—Anticline and quartz vein in gneiss, Washington, Vermont, showing the intense pressure to which the rock has been subjected. Photo. by C. H. Richardson.

Gneiss.—A gneiss is a metamorphic rock of sedimentary or igneous origin. Its mineralogical composition is identical with that of granite. It differs from granite in having its ferromagnesian mineral arranged in parallel layers, instead of being uniformly scattered throughout the rock mass. It therefore is less resistant to compressive stresses than the granites, especially if pressure be applied parallel with the schistosity.

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The names of the different varieties are determined by the prevailing ferromagnesian mineral. If the gneiss results from the shearing of granite masses it is called a granite gneiss and is simply a metamorphosed granite. If it results from the metamorphism of feldspathic sediments it is called a paragneiss. (See Figs. 121 and 122.)

Volcanic Tuff.—A volcanic tuff is a deposit of volcanic ash which has become consolidated. This eruptive occurs as a building stone at Los Berros, San Luis Obispo County, California. The outcrop is on the south side of Los Berros creek.

Fig. 123.—Quarry in volcanic tuff, Los Berros, San Luis Obispo County, California. The material is used for building purposes. Photo. by T. C. Hopkins.

In the quarry two distinct beds of tuff are readily discerned. The upper bed, from 10 to 12 feet thick, thins out toward the west. It lies without any parting on the smooth surface of an older bed, dipping slightly to the east. The upper tuff is of more regular character and harder than the underlying tuff. It breaks in large but irregular blocks. The lower tuff is much harder than the upper, has a metallic ring and breaks in small blocks with curved faces like glass. (See Fig. 123.)

TABLE SHOWING THE SPECIFIC GRAVITY, STRENGTH PER SQ. IN., WEIGHT PER CU. FT., AND RATIO OF ABSORPTION OF GRANITES OF VARIOUS KINDS.

Kind and Locality	Size of Cube, Inches.	Position	Lbs. Strength per Sq. In.	Specific Gravity	Lbs. Weight per Cu.Ft.	Ratio of Absorption	Remarks.
Granite, Penryn, Cal...		Bed	6,117	2.77	173.45	.032	
Granite, Rocklin, Cal...		Bed	5,239	2.68	167.25	.054	
Biotite Granite, Platte Canon, Colo...	2.00x2.00	Edge	14,634	2.625	163.747	.006	
Granite, Gunnison, Colo...	2.04x2.06	Bed	12,976				
Do...	2.02x2.04	Edge	15,594	2.715	169.361	.006	Broke suddenly without cracking.
Biotite Granite, New London, Conn...	2		12,500	2.660	166.25		
Do...	2	Edge	14,175	2.660	166.25		
Granite, Milford, Conn...	5.93x5.97		22,610				Average of 2 determinations broke suddenly without cracking.
Biotite Granite, Vinalhaven, Me...	2		13,381	2.660	166.3		Average of 6 determinations broke suddenly without cracking.
Do...	2	Bed	15,698	2.608	163.		Burst suddenly.
Do., Fox Isle, Vinalhaven, Me...	2	Bed	14,875	2.631	164.1		
Do., Hurricane Isle, Me...	2	Bed	14,425	2.670	166.9		
Hornblende Granite, E. St. Cloud, Minn..	2	Edge	28,000	2.692	168.2	Trace	
		Bed	26,250				
Do., East St. Cloud, Minn...	2	Edge	28,000	2.609	163.1	.0047	
		Bed	26,250				
Biotite Granite, Ft. Deposit, Md...	2	Edge	19,750				Coarse: strongly dashed with black.
Do...		Bed	13,100	2.720	170.		Average of 2 determinations.
Do...		Edge	15,750	2.720	170.		Broke suddenly without cracking.
Hornblende Granite, Cape Ann, Mass...	2	Bed	12,423				Broke suddenly without cracking.
Do...	2	Bed	19,500				Cracked before bursting.
Do., Rockport, Mass...	2	Bed	16,300	2.610	163.2	.0065	
		Edge	19,750				
Do., Quincy, Mass...	2		17,750	2.660	166.2		
Biotite Granite, Westerly, R. I...	2	Bed	14,687	2.670	166.9		Broke suddenly without cracking.
Do...			17,184				
Biotite Granite, Richmond, Va...	2	Bed	14,100	2.630	164.4	.0029	Broke suddenly without cracking.
		Bed	13,875				
Hornblende Granite, Bay of Fundy, N. B.	2	Edge	11,196	2.600	162.5		Average of 2 determinations.
Gabbro, Duluth, Minn...	2	Edge	17,187				
Granite, Bethel, Vt...	2	Bed	33,153				

REFERENCES

Buckley, E. B. Building and Ornamental Stones of Wisconsin; Bull. Geol. Survey, No. 4, Madison, Wis., 1898.

Coons, Altha T. The Stone Industry in 1904. Min. Res. U. S., 1904.

Dale, T. N. The Granites of Maine; Bull. 313, U. S. G. S., 1907.

Dale, T. N. The Chief Commercial Granite of Massachusetts, New Hampshire and Rhode Island; Bull. 354, U. S. G. S. 1908.

Dale, T. N. The Granites of. Vermont; Bull. 415, U. S. G. S., 1909.

Daly, R. A. The Geology of Ascutney Mountain, Vt.; Bull. 209, U. S. G. S., 1903.

Day, W. C. Stone; Min. Res. U. S. G. S., 1899.

Harris, G. F. Granite and Our Granite Industries; London, 1888.

Howe, J. A. The Geology of Building Stones; E. Arnold, London, 1910.

Hull, E. A. Treatise on the Building and Ornamental Stones of Great Britain and Foreign Countries; London, 1872.

Lewis, J. V. Building Stones of New Jersey; N. J. Geol. Survey, 1908.

Mathews, E. B. The Granite Quarries of Maryland; Rept. of Maryland Geol. Sur. Vol. 2, 1898.

Merrill, G. P. Stones for Building and Decoration; J. Wiley and Sons, 1902.

Parks, W. A. The Building Stones of Canada; Can. Mines Branch, Vol. I: Rept. No. 100 (Ontario); 1912. Vol. II: Rept. No. 203 (Maritime Provinces); 1914. Vol. III: Rept. No. 279 (Quebec); 1914. Vol. IV: Rept. No. 388 (Western Provinces); 1916.

Perkins, G. H. Report on the Marble, Slate and Granite Industries of Vermont; 1898.

Richardson, C. H. Areal and Economic Geology of Northeastern Vermont; Rep. of Vermont State Geologist, 1905-1906.

Richardson, C. H., A. E. Brainerd and D. J. Jones. The Geology and Mineralogy of Hardwick and Woodbury, Vt.; Report of Vermont State Geologist, 1914.

Ries, H. Economic Geology; John Wiley and Sons, 1916.

Ries, H., and T. L. Watson. Engineering Geology, John Wiley & Sons, 1914.

Tarr, R. S. Economic Geology of the United States, with Briefer Mention of Foreign Mineral Products; New York, 1895.

Watson, J. Building Stones; Cambridge University Press, 1911.

Watson, T. L. A Preliminary Report on a Part of the Granites and Gneisses of Georgia; Bull. 9A, Georgia Geol. Survey, 1902.

CHAPTER IV

LIMESTONES, DOLOMITES AND MARBLES

Definition.—A limestone is any rock mass consisting essentially of calcium carbonate, $CaCO_3$, or of calcium carbonate intermingled with more or less magnesium carbonate. The calcium carbonate has been separated from water, rendered insoluble and accumulated by the action of living organisms of various kinds. Such deposits may be mechanically broken up and redeposited, or they may be taken into solution, carried away and precipitated elsewhere. Some possible exceptions to this rule are cited later under the caption of the origin.

A dolomite is any rock consisting essentially of calcium carbonate and magnesium carbonate, $CaCO_3$, $MgCO_3$. Geologically speaking a dolomite may contain a large amount of admixed calcite. Mineralogically, dolomite means a definite chemical compound of formula $CaCO_3$, $MgCO_3$. Limestones containing more than 5 per cent of magnesium carbonate are dolomitic. The magnesium carbonate of the dolomites has been added to organic limestones which were originally free from, or poor in, magnesia. The unstable forms of calcium carbonate, aragonite and conchite take up magnesia quite readily. According to E. Weinschenk calcite cannot be altered to dolomite. Dolomites are distinctly crystalline, often porous and filled with drusy cavities.

From a geological standpoint a marble is a metamorphosed limestone. It is distinguished from a limestone by its crystallization, coarser grain, compactness and purer colors. If pure, it is often very massive and shows no signs of schistose cleavage, even where its association with schists is such as to indicate that it must have been subjected to enormous pressure and shearing stresses.

Dolomitic limestones pass by metamorphism into dolomitic marbles. We therefore have both calcite marbles and dolomite marbles. A metamorphosed calcareous rock is often called a marble whether it contains magnesia or not. From a petrographical and a chemical standpoint there is an important difference between a calcite marble and a dolomite

marble. This holds especially true in respect to the associated minerals they are apt to contain when impurities were originally present in them. The pure statuary marbles like those of Marble, Colorado, Western Vermont and Carrara, Italy, contain little else than the mineral calcite. Dolomite marbles usually contain some calcite in addition to the dolomite crystals. From a purely commercial standpoint a marble is any limestone or dolomite, whether metamorphosed or not, susceptible of a polish and suited for decorative interior work or the purposes of massive construction.

Impurities.—Limestones vary widely in their composition. They range from 25 per cent $CaCO_3$ to theoretically 100 per cent $CaCO_3$. The impurities are uncombined carbon which imparts a dark gray or black color to the rock, clayey matter which gives limestone a drab or gray color, pyrite, siderite, talc, serpentine, micas, amphiboles, pyroxenes and sand. Greensand marl and phosphatic particles are sometimes present. Bituminous matter and even hydrogen sulphide may be encased in limestones. The former shows the presence of bitumen when heated, and the latter variety emits an offensive odor when struck with a hammer. Such a limestone is represented at Chatham, Canada, and in western Vermont.

Texture.—The texture of the calcareous rocks is as varied as their composition. They range from the soft, friable, fine grained chalk to the compact and crystalline types. As a rule the older formations are the more compact and crystalline, while the younger formations are more apt to be friable.

Varieties.—The numerous varieties are based upon several different factors as structure, chemical composition, mode of origin, uses, etc.

A pure marble consists of calcite crystals in a crystalline, granular aggregation. Saccharoidal marble is a variety that closely resembles loaf sugar in texture. Common compact limestone is often amorphous and homogeneous. A microscopic investigation reveals it to be an aggregation of crystalline calcium carbonate. Hydraulic limestone which has so large a significance from an engineering standpoint is a variety that contains 10 per cent or more of silica and the proper amount of clayey matter to make a cement that when the stone is burned will set under water. Lithographic limestone that has been used extensively in the preservation of stock patterns is a fine grained magnesian variety with its best representative found at Solenhofen, Germany. Oolitic limestone consists of small, rounded, concretionary grains

about the size of the egg of a brook trout. A dolomitic lime-
stone is one containing 5 per cent or more of magnesium
carbonate. In its metamorphism it passes into a dolomitic
marble. A true dolomite, however, would be represented by
the double molecule, $CaCO_3$, $MgCO_3$, which characterizes
some of our most handsome decorative marbles. There is
every stage and gradation between calcite on the one hand
and magnesite on the other. Travertine, known also as cal-
careous tufa, represents a chemical precipitate. Mexican onyx
is a massive variety of travertine that is highly prized for its
translucency and variety of colors. Stalactite is the variety
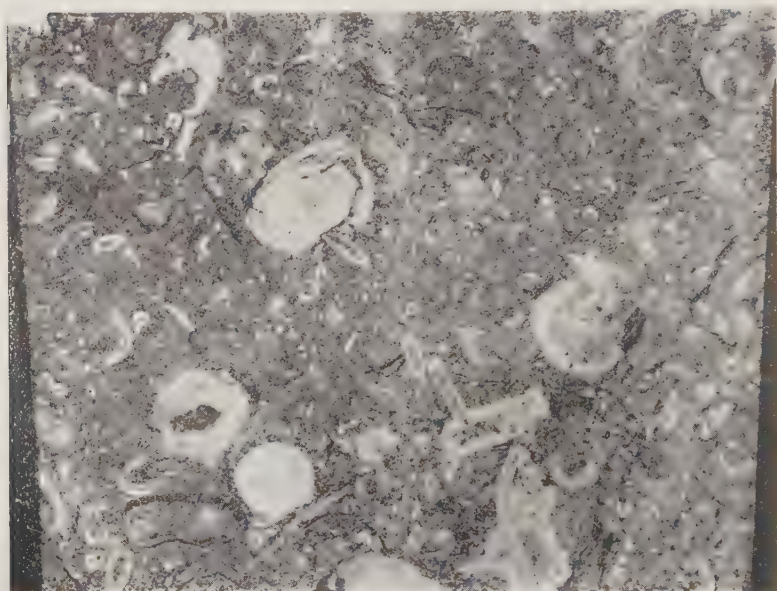
Fig. 124.—Sawn slab of fossiliferous marble. Photo. by C. H.
Richardson.

that forms on the roofs of caves and stalagmite the one that
forms in a similar manner upon the floors of caves. When the
two varieties meet they form a pillar. Coquina is a variety
that consists of broken shells held together by a cement of
lime. The more compact massive forms are used for building
purposes. A coralline limestone is one consisting essentially
of fragments of coral. A fossiliferous limestone is one con-
taining any identifiable fragment of the testa of some former
animal. Such limestones are named from the prevailing

species present, as crinoidal limestone when the fossils are the fragments of crinoidal stems. (See Figs. 124 and 125.)

Origin.—The origin of limestones, dolomites and marbles is very diverse. The primary source is to be found in the decomposition of igneous rocks by carbonated waters. Calcium carbonate is taken into solution in ground water, springs and rivers, and subsequently withdrawn from solution by a variety of processes. It is deposited as a chemical sediment from hot springs and sea water and often precipitated as a cement in other rocks.

Waters charged with carbon dioxide become a potent solvent for rock constituents. This effect is illustrated by the limestone caves in Kentucky and the Luray Caverns in Vir-
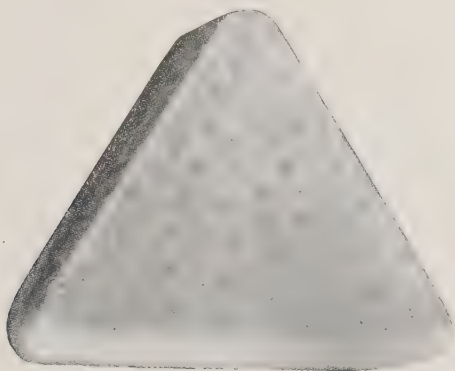
Fig. 125.—Cross section of coralline marble, Iowa City, Iowa. Photo. by C. H. Richardson.

ginia. The surchaged waters when relieved of pressure deposit their load in some of the various forms of travertine. The stalactitic and stalagmitic marbles fall into this class. By this process also large masses of the compact variety known as onyx are produced.

Rivers flowing over limestone areas carry a certain amount of calcium carbonate in solution into the sea. A direct precipitation of this calcium carbonate can occur only when the supply of carbonate is in excess of that which can be consumed by living organisms and when the conditions of temperature and pressure are such as to expel the solvent, CO_2. Such deposits are exceptional rather than common. According to Sir Charles Lyell this condition exists in the delta of the Rhone, and Bailey Willis cites the precipitation of lime-

stones along the margin of the Everglades in Florida, where the inflowing waters are exposed in broad, shallow sheets to evaporation, agitation, and variations of temperature and pressure. The calcium carbonate is partly thrown down as mud and partly deposited on the underlying limestones as a layer of rock. G. P. Merrill states in his "Stones for Building and Decoration" that the alternation of beds of snow-white, blue-gray, greenish and almost black layers in the Vermont marbles may perhaps be best explained on the assumption that the white layers were deposited from solution and the darker layers were beds of indurated shell mud and sand colored by the organic impurities they contained at the time they were first laid down.

According to I. C. Russell great masses of calcareous tufa have been deposited around Pyramid and Winnemucca Lakes in Nevada. When the deposits assume the form of oolitic sand the carbonate is deposited around sand grains or other foreign bodies as nuclei. G. K. Gilbert cites similar formations around Great Salt Lake but only where there is much agitation of the waves. The tufa requires surf to discharge the excess of carbon dioxide and deposit calcium carbonate. A Rothpletz attributes the formation of oolitic sand at Great Salt Lake to minute algae. F. Cohn, through his investigations of the travertine deposits of the waterfalls of Tivoli, attributes the deposition of the calcium carbonate to species of thallophytes, as Chara, and bryophytes, as mosses, that are capable of extracting carbon dioxide and setting free calcium carbonate. When they do this in the presence of the bicarbonate they deprive that salt of the second molecule of carbonic acid and the neutral carbonate is thrown down. The material, at first porous, is afterwards transformed into a compact rock by the deposition of calcite in its interstices.

W. Kitchell attributes the formation of fresh water marls in New Jersey to the presence of algae. C. A. Davis recognizes the function of Chara in the formation of certain marl deposits in the lakes of Michigan.

G. H. Ashley and W. S. Blatchley also recognized the activity of aquatic plants in the formation of the marl deposits of the lakes in Indiana. The smaller morainal lakes of central New York are rapidly filling up with marl deposits. These lakes are comparatively shallow and many of them have their waters constantly aerated by strong wave-producing winds. The waters that serve as feeders for the lakes flow over limestone areas and carry much calcium carbonate in solution into

them. The lakes are rich in their aquatic plants which consume carbon dioxide and exhale oxygen. The activity then of algae may be a potent influence in the formation of the marl deposits. See John M. Clarke's paper on the Water-Biscuit of Squaw Island, Canandaigua Lake.

G. Steinmann has pointed out that albumen which is present in the organic parts of all aquatic plants may serve as a precipitating agent. F. W. Clarke suggests that albuminoids generate ammonium carbonate by fermentation and to that compound the precipitation of calcium is due. P. F. Kendall has shown that waters charged with carbon dioxide dissolve aragonite far more rapidly than calcite, and that aragonite shells largely disappear while calcite organisms remain permanently in fossil form. He also found that calcitic globigerina ooze appears in waters at a depth of 2,925 fathoms and that aragonitic pteropod shells practically disappear at depths exceeding 1,500 fathoms. Kendall concludes that as the Upper Chalk beds of England carry only calcitic organisms they must have been deposited in waters exceeding 1,500 fathoms in depth. At temperatures exceeding 60 degrees aragonite is more apt to be formed and that below that temperature calcite. As coral life demands temperatures exceeding 68 degrees aragonite may form and later become calcitized.

According to E. W. Skeates both aragonite and calcite occur in the coral formations. The formation of a coralline limestone may be followed easily in the fringing reefs, barrier reefs and atolls. The order is as follows: (1) The living animal, the coral polyp. (2) The dead animal with its home broken into fragments by the waves. (3) Cementation of these broken fragments by the solution and redeposition of a part of the calcium carbonate. (4) The solid rock composed of these organic remains. Such limestones may bear both calcite and aragonite, deposited directly from the sea water. Both organic matter and earthy matter may be present. S. P. Sharples found in the corals of the Gulf Stream from 0.28 to 0.84 per cent $3CaO$, P_2O_5. Dolomitization of coralline limestones may be effected through magnesium-bearing waters.

The coquina of Florida and many other sea beaches affords illustrations of limestone building from shells. These broken fragments are cemented together by calcium carbonate which has been deposited from solution in the interstices between the shells. In one instance as cited by W. H. Dall the cement was limonite deposited by a chalybeate spring. Quartz sand may be commingled with the shell material. J. A. Howe in

his "Geology of Building Stones" cites brachiopods, pelecy-
pods, gastropods, pteropods and cephalopods as limestone
builders.

Crinoidal limestones are formed from the disjointed frag-
ments of the stems and arms of crinoids or sea lilies. The
cross sections of such fragments vary from a small fraction of
an inch to an inch or more in diameter. The smaller frag-
ments have given rise to the decorative stone known as
birdseye marble. This name has also been applied to some
of the coralline limestones of Iowa. (See Fig. 126.)

Oceanic ooze may be laid down on the floor of the sea and
compressed into a soft rock like the chalk cliffs of England.
This material may be practically free from impurities. The
sediments may be rich in clay or mud and produce a fine
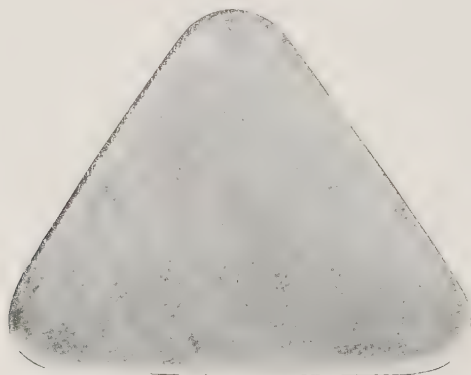
Fig. 126.—Cross section of fine grained coralline marble from Iowa
City, Iowa.   Photo. by C. H. Richardson.

grained argillaceous limestone with every shade and grada-
tion between a calcareous shale and a pure limestone. The
sediments may contain also quartz grains, largely calcareous,
and produce a limestone that is fine grained and hard. These
rocks shade imperceptibly from siliceous limestones into cal-
careous sandstones. An illustration of this transition is found
in the limestone belt of central and eastern Vermont.

Marbleization.—The marbleization of calcium carbonate, or
the conversion of amorphous carbonate into a crystalline lime-
stone or marble, may be effected in a number of ways as
shown by the experiments of Sir James Hall, G. Rose, A.
Becker, A. Johannis, H. E. Boeke and H. Le Chatelier. In
these experiments both temperature and pressure have been
widely varied.

Pressure alone, either long continued and gentle, or heavy and of short duration, may produce this change. It may be brought about by the influence of heat. Both heat and pressure may work conjointly in effecting the marbleization of amorphous calcium carbonate. Actual fusion of the lime carbonate is unnecessary. Water plays an important part in the process for in geological phenomena its influence is rarely excluded. The solution and redeposition of calcium carbonate explains many changes in the structure of calcareous rocks.

Alteration.—Changes in limestones may be effected by an infiltration of waters bearing silica in solution. By the deposition of the silica the stone becomes silicified. A limestone may become phosphatized by the action of meteoric waters flowing over beds of guano. It may become gypsumized through the decomposition of inclosed pyrite and the acid sulphates formed through such decomposition. The most potent change is effected by waters charged with carbon dioxide. Impure limestones yield a large number of objectionable minerals through thermal metamorphism. Organic matter furnished the necessary material for the scales or plates of graphite in the limestones of northern New York. Silica provided the material for the limpid crystals of quartz found in the cavities of the Carrara marble of Italy. Silica may unite also with a part of the lime present, in the formation of such calcium silicates as wollastonite and scapolite. The hydroxides of iron may yield hematite or through reduction magnetite. The hydroxides of aluminum may form corundum or even ruby, the red gem variety of corundum, as in Burma. When both silica and alumina are present there occurs a reaction between them and a part of the calcium carbonate with the formation of several silicates of calcium and aluminum like garnet, vesuvianite, epidote, etc. The feldspars, micas, amphiboles and pyroxenes may appear along contact zones or as inclusions within the metamorphic limestone itself. Phlogopite is characteristic of many limestones or marbles that originally bore magnesia and silica in the presence of iron compounds. Magnesia alone may crystallize out as the oxide, periclase. When both magnesia and alumina are present spinel is formed. With magnesia and silica enstatite would appear. With magnesia, silica and iron, minerals like olivine, bronzite, hypersthene, etc., appear. According to J. F. Kemp the Adirondack limestones were originally siliceous

dolomites in which the silica and magnesia segregated as pyroxenes.

Dolomite.—The terms magnesian limestone, dolomitic limestone and dolomite are used to designate any calcareous rock containing a high proportion of magnesia. A limestone containing more than 5 per cent $MgCO_3$, is often spoken of as dolomitic. The term superdolomite is often used to denote rocks with a large content of magnesium carbonate and a small content of calcium carbonate. This term would cease with less than 5 per cent $CaCO_3$ and the rock would pass into magnesite. In the magnesian rocks there is every gradation possible between the pure calcite, $CaCO_3$, on the one hand and magnesite, $MgCO_3$, on the other.

The true dolomite falls between these extremes where the ratio approximates to that of the mineral bearing the name dolomite. In this mineral the calcium carbonate represents 54.35 per cent and the magnesium carbonate 45.65 per cent. Dolomites may occur either as an alteration product within a normal limestone or a chemically deposited rock. Dolomitization may occur while the fresh limestone or ooze is in the sea in which it is formed. This has been observed in the borings from coral islands. It is called contemporaneous dolomitization. Subsequent dolomitization may occur after consolidation and uplift of the original material into a land mass. Waters bearing in solution magnesium carbonate as they traverse limestones exchange their less soluble magnesium carbonate for the more soluble calcium carbonate, molecule by molecule, and thereby the rock mass gradually becomes dolomitized. Recent experiments show that marine organisms secrete more magnesium than was formerly supposed.

The existence of dolomites as true chemical sediments is comparatively rare. According to J. A. Howe the Mansfield, England, dolomite falls into this class. G. Leube cites a fresh water dolomite near Ulm, Bavaria. According to T. Scheerer the oldest dolomites were formed as chemical precipitates. The experiments of T. Sterry Hunt also show the possible precipitation of dolomite.

Hot springs containing magnesium carbonate have been shown by J. E. Spurr as potent factors in the dolomitization of the limestone rocks around Aspen, Colorado. Where limestones are intruded by peridotites such dolomitization may be expected. In the absence of the limestones the transition may be to a siliceous magnesite as in Troy, Vermont.

According to F. W. Pfaff the products of organic decomposition such as carbon dioxide, ammonium carbonate, ammonium sulphide and hydrogen sulphide play an important part in the process of dolomitization. Carbon dioxide acting for a considerable period of time upon the chlorides and sulphates of calcium and magnesium produces a double carbonate of the two bases. This condition is practically paralleled in the concentration of sea water. Therefore by this process dolomite may be formed.

F. W. Clarke has suggested that algae may precipitate dolomite or the mixed carbonates as they do calcareous marl. It is apparent then that dolomite may be formed by various processes and possess different modes of occurrence.

Dolomite Tests.—(1). Calcite effervesces freely in the presence of cold dilute HCl. Dolomite effervesces feebly under
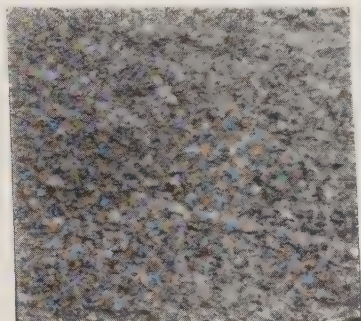
Fig. 127.—Polished slab of quartzose marble from quarry of Huntington and Clough, Washington, Vermont. Photo. by C. H. Richardson.

the same condition. Magnesite similarly treated should suffer no immediate change.

(2) Calcite when treated with a solution of aluminum chloride and haematoxylin (extract of logwood) receives a violet coating. Dolomite under the same condition remains uncolored.

(3) Pulverize a few grams of rock suspected to be dolomite. Cover with water and add a few drops of phenolphthalein solution. Calcite gives a strong coloration. Dolomite is but slightly tinted.

Color.—Limestones, marbles and dolomites possess a wide range of colors. They shade from the pure white like the statuary marble of western Vermont to a jet black like that

of Glens Falls, New York The cream, buff, brown, orange and red tints are produced by varying amounts of the oxides of iron, either in a hydrated or anhydrous condition. The blue and some of the gray colors are produced by finely divided carbonaceous matter. Clayey matter often presents a drab or gray appearance in a limestone. Iron disulphide in granules of microscopic size may produce a gray color. Uncombined carbon in the larger amounts produces a black.

Hardness.—The hardness of the calcareous building stones varies widely. Calcite alone is only 3 in hardness. Statuary marbles possess the same degree of resistance to abrasion. The state of aggregation of the individual grains affects the hardness. The coquina of Florida, the coralline rocks of the reefs of many islands and the Caen marble of France are extremely soft. The Bedford oolite is of medium hardness. The siliceous limestones of Vermont are extremely hard and cut to a fine edge. (See Fig. 127.)

Specific Gravity.—The specific gravity of limestones and marbles varies from 2.7 to 2.9. Its weight per cubic foot is a little higher than that of the average granite. With the higher specific gravity the weight would be 181 lb. per cu. ft.

Distribution.—Some form of the calcareous building stones is found in nearly all states and practically in all countries of the world. Many of these are used only locally if at all. Some have found favor both at home and abroad. The Bedford, Indiana, oolitic limestone, the marbles of western Vermont and Carrara, Italy, fall into this class.

Age.—The limestones, marbles and dolomites do not belong to any particular age. They are found in formations ranging from the Archaean to the Tertiary. Lime bearing formations are accumulating at the present time.

AMERICAN LIMESTONES AND MARBLES

The various states producing calcareous rocks will here be considered in alphabetical order.

Alabama.—Prof. W. F. Prouty of the University of Alabama has kindly contributed the description of marbles from that state.

The marbles of Alabama may be classified as follows, viz: (1) The variegated, red and green varieties of Cambrian age from near Calera, Shelby County. (2) The pink semi-crystalline marble of Ordovician age from near Pratts Ferry, Bibb County. (3) The gray semi-crystalline

marble from the sub-Carboniferous terranes of Jackson County. This marble very closely resembles the McMullan gray marble of the Knoxville district in Tennessee. (4) The black marble from the carbonaceous crystalline limestones of the Knox dolomite formation in Calhoun County. (5) The onyx marble from near Childersberg, Talladega County. (6) A white crystalline marble, constituting the chief marble deposits of the state, which varies in age apparently from Middle Cambrian to Lower or Middle Ordovician. (See Figs. 128 and 129.)

The crystalline white marbles of Alabama are being rapidly developed at the present time. These marbles are bringing this state into prominence as a marble producer. It has however been known for many years that good marble de-

Fig. 128.—Polished sample of cream No. 1 marble from Gantt's quarry, Alabama. Photo. by C. H. Richardson.

posits existed in this state. Small quarries were opened and the product used for monumental purposes. These monuments have given to posterity the evidence of their long life and beauty. These facts are responsible in no small measure for the recent development of the marble industry in Alabama. Monuments and tombstones set sixty years ago which have been exposed to the most extreme weathering agencies of that climate still preserve on their surfaces the very finest lines of carving and lettering.

Texture.—On the average the Alabama marbles are a little finer grained than the crystalline marbles of Vermont. The grains are also more interlocked. As a result of this fact the

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Alabama marbles have a slightly greater resistance to compression, a higher tensile strength and a greater sonorousness. Their translucency is unusually high. The chief impurities are the light green talc layers, or schist bands, which mark the original bedding planes. Some of the beds of marble have a bluish tone but for the most part the marketed product is a cream toned white with, or without, the coloring due to the presence of the schist bands. (See Figs. 130 and 131.)

Uses.—Most of the Alabama Marble is sawed into thin slabs for interior wainscoting as it seems best suited for this type of ornamentation. It is also used for all kinds of interior and exterior construction.

Fig. 129.—Polished slab of grade A marble from Gantt's quarry, Alabama. Photo. by C. H. Richardson.

Quarries.—At the present time there are four quarries in active operation. The main one is located in about the center of the marble field. It has a large mill for finishing the marble. The other quarries either send their product direct to this mill for manufacture or sell the stone in the block form for $2.00 per cu. ft., or even more. Most of the product sent to New York City is uncut on account of the organized labor there which demands local finishing of the stone. (See Figs. 132, 133 and 134.)

Structural Relations. — The crystalline marbles of Alabama occur in a long, narrow and more or less well defined valley which is about 35 miles in length and from a quarter of a mile to a mile and a half in breadth. The Ocoee phyllite

bounds the valley on the east. The marble is separated from the phyllite for the greater length of the field by a thrust fault. The marble bearing rocks in this so called marble valley are also separated from the rocks on the west side of

Fig. 130.—Polished sample of cream B marble from Gantt's quarry, Alabama. Photo. by C. H. Richardson.
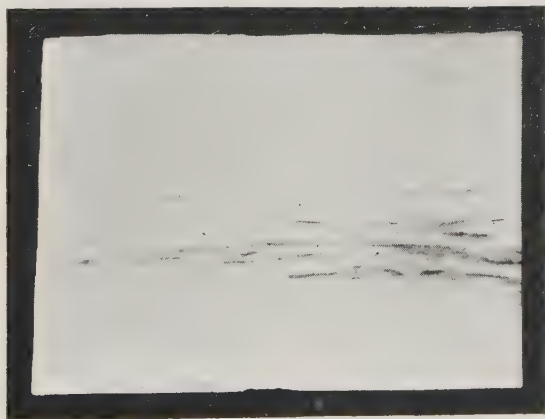
Fig. 131.—Polished slab of Pocahontas marble from Gantt's quarry, Alabama. Photo. by C. H. Richardson.

the area in many places by a fault. The marble beds have in some places a strike at variance to the general trend of the valley. This is especially true in the part of the marble area where the marble bearing rocks reach their maximum width.

Through this portion of the field the marble bearing rocks constitute a fault block. The general dip of the rocks is always in an easterly direction and at an angle of about 30 degrees. (See Fig. 105.)

Age.—The age of the marble beds is apparently different in the different portions of the field. It ranges from Lower Cambrian to Ordovician. There is no definite paleontological

Fig. 132.—Gantt's quarry Alabama, looking southwest and showing a fold in the rock which runs diagonally down the dip. Photo. by W. F. Prouty.

evidence for assuming this age. The assumption is based upon the character of the associated terranes.

Topography.—There is not a natural rock exposure throughout the entire length of the field save in places where it has been faulted up or exposed in the bed of the streams. The topography of the area is not only interesting but it also tells

much concerning the character of the stones below the soil cover. The Ocoee phyllites on the east make bold hills which descend rapidly into the marble area to their west. The dolomites which often border the marble area on their west occupy a slightly greater elevation than that of the calcitized marbles. In their decomposition they form a soil of much deeper red color. The above statements also hold true of the dolomites that strike diagonally across the valley.

Bedding.—In most places the schistosity bedding as shown by the schist lines is practically identical with the bench

Fig. 133.—View of the sawing sheds at Gantt's quarry, Alabama. Photo. by W. F. Prouty.

joints. In other places however the variation is as much as 15 degrees between these two planes. This is in part due to the drag folding of the layers during lateral movement. The direction of the movement that caused this folding is usually plainly shown on the slipping planes and may be seen in some cases in the elongation of the crystals in that direction as studied under the microscope.

Jointing.—A study of the system of jointing in Gantt's

quarry shows that there are two distinct series of master joints. One set is at approximately 45 degrees to the direction of movement. The other set is at right angles to this direction. There is also a slight radiation in the direction of the joints which was apparently caused by the tortional strains set up in the rock during deformation.

Quarrying.—The method of quarrying marble in Alabama differs markedly from that followed in Vermont and Georgia. Instead of quarrying on the level floor the blocks are taken
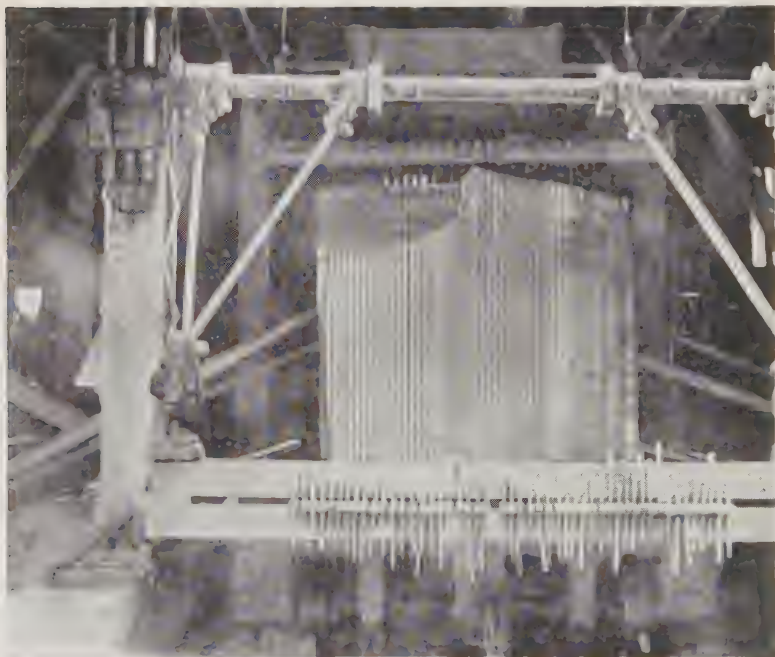
Fig. 134.—Sawing marble in the mill at Gantt's quarry, Alabama. Photo. by W. F. Prouty.

out parallel to the dip. This method is made necessary on account of the nature of the dip of the marble and the less metamorphosed and compacted nature of the deposits. Tunnelling is resorted to in the Gantt's quarry. This enables the securing of a greater floor space with less expenditure of money. It also insures a higher percentage of sound marble because of its position below the most active zone of weathering. The so-called slicks or vertical joints which

run down the dip are greatly reduced in number and often almost absent in the deeper portions of the quarry. At a depth varying from 75 to 100 feet a much greater percentage of sound marble is produced than at altitudes nearer the surface. The percentage of sound marble that can be obtained in a given quarry is much smaller than it is in Georgia. In Alabama the usual quarry run of sound marble is between 20 and 30 per cent. In quarries where the joints run at 45 degrees with the dip, and the strike joints are of secondary importance, a much higher percentage of marble can be secured by taking out the blocks with the long cuts parallel to the main or 45 degree joints. This method reduces the very wasteful diagonal unsoundness in the blocks. See Fig. 136.)
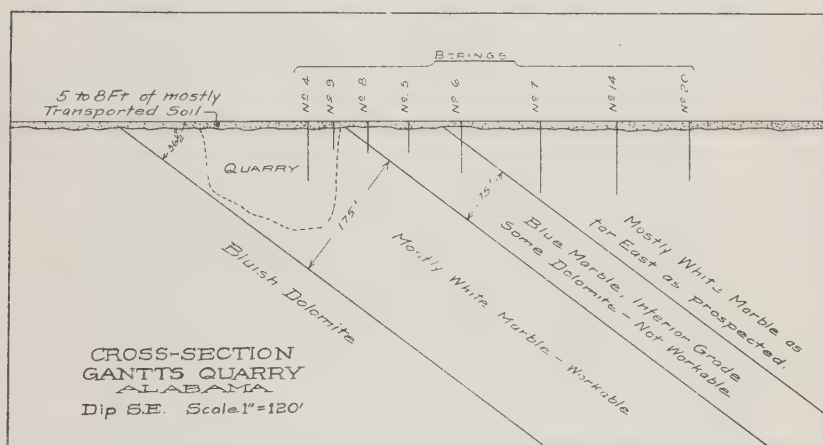
Fig. 135.—Cross section of Gantt's quarry, Alabama. Drawing by W. F. Prouty.

There are apparently several layers of the marble inter-bedded with dolomite as in the case of the Vermont deposits. In places the dolomite beds lens out completely. A careful microscopic study of the line of contact between the dolomite beds and the calcite beds shows that there are always, as far as seen, sharp lines of demarcation between them. If the dolomites are replacement products there must have been at the time of their replacement a very marked favoritism on the part of the magnesian salts towards these unfortunate layers.

Thickness.—The thickness of the deposits at the Gantt's quarry is clearly shown in Fig. 137.

Arizona.—Three distinct types of marbles are quarried in Arizona. They are used for decorative purposes. They are classified as (1) Arizona Opal which shades from white through cream yellow and pink. (2) Arizona Pavonazza which shades from creamy white to pink with strong black

Fig. 136.—Gantt's quarry, Alabama, looking northeast into narrow opening. Photo. by W. F. Prouty.

veins. (3) Arizona Pavonazza, heavy veined. Pavonazza marbles are of creamy tint and may not be veined.

Arkansas.—According to J. C. Branner the northern part of Arkansas is covered with a large belt of Ordovician marbles which occur in beds varying from ten to one hundred feet in

thickness. Blocks of any dimension desired can be obtained. The marbles shade from white through pink to red. (See Fig. 138.)

California.—The limestones of California are widely distributed throughout the state. No very extensive area is without them, yet the areas themselves are not extensive. In thickness the beds are sometimes several hundred feet.

Fig. 137.—View showing the initial stages of a tunnel in a marble quarry in Alabama. Two tunnels are now utilized to increase the floor space of this quarry. Photo. by W. F. Prouty.

They are most prominent in Kern, San Bernardino, San Diego and Santa Cruz Counties. They were formed under different conditions and vary in texture and composition. They vary in color from white to blue. Some of them are used for building stone and others as decorative marbles. The large uses

of the limestones proper are in the beet sugar industry, the manufacture of lime and Portland cement.

According to T. C. Hopkins marble is produced in California in Amador, Inyo, Riverside, San Bernardino and Tuolumne Counties. Some of the marbles are white, clouded, variegated and others are of the onyx type. The beds in Amador County vary in thickness from 100 to 200 feet. The stone is light gray and blue in color. In Inyo County the stone is a dolomite. The chemical analysis gives calcium carbonate 54.25 per cent, and magnesium carbonate 44.45 per cent. The marbles are white, yellow, gray and black. The black is used in floor tilings. (See Fig. 139.)

Fig. 138.—Red marble quarry, Eureka Springs, Arkansas. Photo. by T. C. Hopkins.

California Onyx.—The onyx marbles of California are noted for their perfect homogeneity of texture, microcrystalline structure, degree of translucency and remarkable beauty. (See Fig. 140.) Some of them are deposited by hot springs, some by cold springs, while others are cave deposits. The finest and best varieties consist of aragonite while others are calcite. The largest and best deposit of onyx is found in San Luis Obispo County. Hopkins also states that the onyx layers are

irregular and vary in thickness from one to thirty inches. In some instances the layers are white, massive and compact and take a fine polish. Others are banded or variegated. In a few cases the seams are filled with hematite which makes bright red blotches, or bands while other portions of the stone are banded with a dark green color. The California onyx is considered by many to be superior to any other quarried or mined
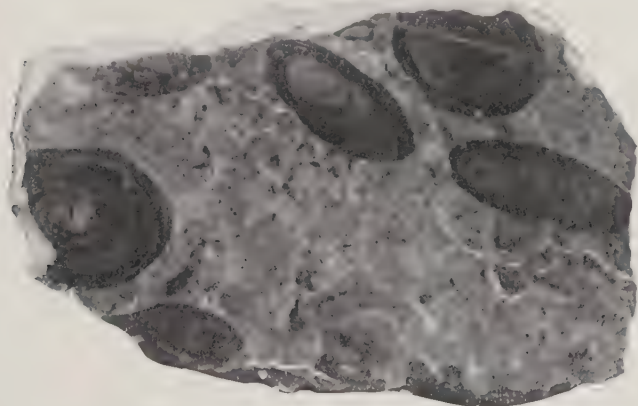
Fig. 139.—Polished slab of variegated marble, Bagdad, California. Photo. by C. H. Richardson.
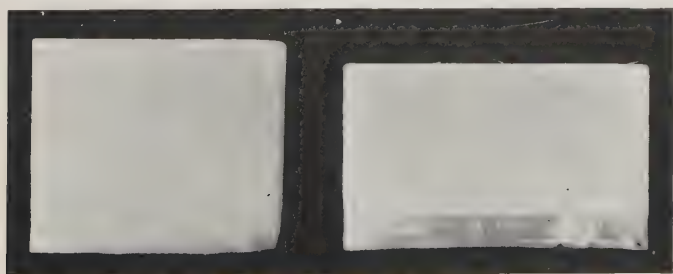
Fig. 140.—Polished slabs of onyx marble, San Luis Obispo County, California. Photo. by C. H. Richardson.

in the world. Verd antique marbles which in reality are serpentines are also produced in California. (See Fig. 141.)

Colorado.—The marble deposits of Marble, Colorado, are 100 feet in thickness and some six miles in length. Some of this stone is exceedingly fine grained and pure white in color. It receives a fine polish and competes with the pure white

statuary marble of West Rutland, Vermont, the Carrara, Italy, and those from the Island of Paros in the Grecian Archipelago. A part of the deposit is tinted or veined with some hydrated oxide of iron a golden yellow. This stone is classified as the golden vein. (See Figs 142 and 143.)

The author has in his private collection several samples of most beautiful sienna marbles from Colorado. They appear equal in every respect to the foreign siennas. (See Fig. 144.)

Connecticut. — The first attempt to quarry marble in a a systematic manner in the United States was made at Marble-

Fig. 141.—Verd antique marble quarry, Victorville, San Bernardino County, California. Photo. by T. C. Hopkins.

dale in the town of Milford about 1800. Although many quarries have been operated from time to time they are now abandoned. In the town of Canaan in the same county of Litchfield is found a coarse crystalline dolomite that is white in color and for many years it was extensively quarried and highly prized for structural purposes. The State House at Hartford, Connecticut, was built of this stone. It bears one objectionable impurity, tremolite. The surfaces of many buildings constructed of this stone have become pitted

through the loss of the crystals of tremolite. Tremolite as elsewhere noted often changes its color upon exposure to the atmosphere. (See Fig. 145.)
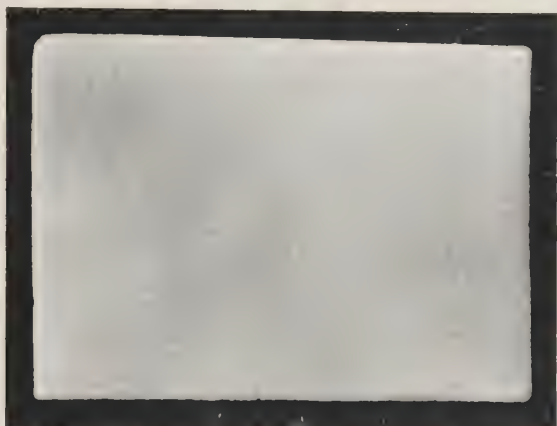
Fig. 142.—Polished slab of Colorado yule marble, Marble, Colorado. Photo. by C. H. Richardson.
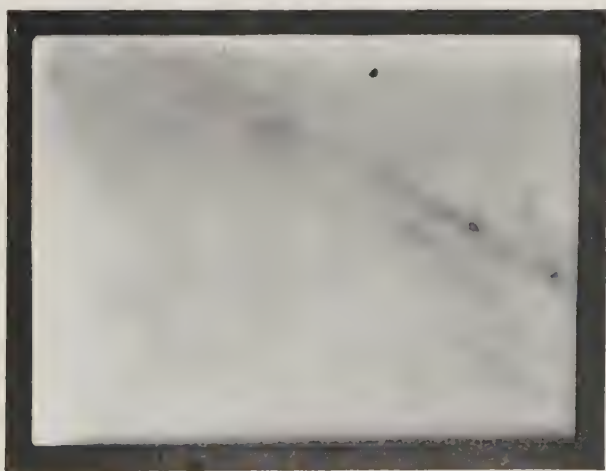
Fig. 143.—Polished slab of gold vein marble, Marble, Colorado. Photo. by C. H. Richardson.

Delaware.—A coarse white dolomite occurs at Hockessin, New Castle County. It is better suited for constructional purposes than it is for decorative work.

Florida. — This state has been somewhat noted for its peculiar variety of structural material known as coquina. These cemented fragments of shells were used largely in the cities of St. Augustine and Fort Marion. The best representative of this stone is found on the Island of Anastasia about two miles from St. Augustine. Coquina is fairly serviceable in Florida but it would not weather well in northern climates
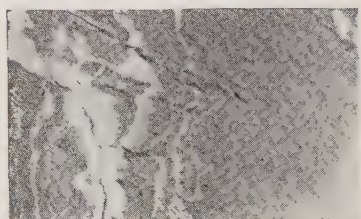
Fig. 144.—Polished slab of sienna marble from Colorado. Photo. by C. H. Richardson.

Fig. 145.—State House, Hartford, Connecticut. By courtesy of S. H. Camp.

on account of its great porosity. At Key West there occurs a soft oolitic limestone that has been quarried to some extent.

Georgia.—The most important marble belt in Georgia lies in the northern part of the state in Cherokee and Pickens Counties. These marbles are of uniform texture but much coarser than the Vermont marbles. They shade in color from

a pure white to blue and variegated. They take a fine polish and many of them are beautiful. The pink variety is unique as well as beautiful. In many ways it is unlike any other known marble in this country. A chocolate red variety is found in Whitfield County. Georgia Marbles are practically pure calcite. They work easily and owing to the mildness of the climate the quarries can be operated safely during all seasons of the year. The commercial names given to these marbles are Cherokee, which is a white calcite; Creole, which is coarse grained, black and white mottled; Etowah, which is coarse grained and flesh colored; Silver Gray Cherokee,

Fig. 146.—State House, Providence, Rhode Island, built of white marble from Georgia. Photo. by C. H. Richardson.

which is in reality bluish gray; Southern, which is nearly white with bluish gray markings. The State Capitol of Providence, R. I., represents Georgia white marble. (See Fig. 146.)

Idaho.—A small amount of marble to supply local demands is quarried at Spring Basin in Cassia County.

Iowa.—The State of Iowa furnishes three widely different types of marble. That furnished by Marshall County near

Le Grand is popularly known as Iowa Marble. It is dolomitic and contains massive beds beautifully veined with the oxides of iron. The stone is prized for decorative work but does not weather well on exposure to the atmosphere.

The Madrepore marble occurs in the vicinity of Charles City in Floyd County. It is a dolomitic rock of Devonian age. Certain strata furnish a coralline marble that is unique and beautiful. Stromatopora fossils are abundant. The
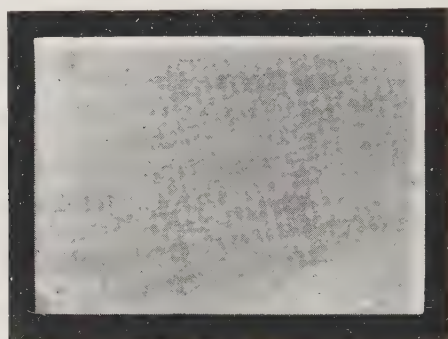
Fig. 147.—Longitudinal section of a small block of coralline marble, Iowa City, Iowa. Photo. by C. H. Richardson.

Fig. 148.—Cross section of coralline marble, Iowa City, Iowa. Photo. by C. H. Richardson.

ground mass of the stone is a light drab but the fossils vary in color from a yellowish brown to a deep mahogany. The stone receives a high polish and is quite unlike any other marble in the world.

The birdseye marble of Iowa City is not oolitic as might be implied by its commercial name. The coral, Acervularia

davidsoni, constitutes the main mass of the stone. The corals are perfectly cemented together by the deposition of calcium carbonate from solution so that the stone receives a high polish and is well suited for decorative work, provided blocks of desired dimensions could be obtained. The writer has many polished samples of this unique stone which are indeed beautiful. (See Figs. 147 and 148.)

Fig. 149.—Lyman Hall, Syracuse University, Syracuse, New York. The base course represents Gouverneur marble and the central courses oolitic limestone from Bedford, Indiana. By courtesy of Syracuse University.

Illinois.—Adams, Cook, Kankakee, Madison and Will Counties furnish a small amount of limestone for structural purposes. Many of the quarries are fine grained, even textured and of light gray color.

11

Indiana.—In this state Lawrence, Munroe and Owen Counties are the largest producers of limestone. The Bedford oolite, named from the quarries at Bedford and its oolitic structure, has justly won a wide reputation as a desirable structural stone. The stone grades from fine to medium in texture and from blue to buff in color. Sometimes these colors are mixed. The oolitic texture is generally pronounced but sometimes the rock is made up of minute fossils. The stone is extremely soft when quarried but hardens upon exposure to the atmosphere. It works easily and the finer varieties are suitable for ornamental work. The stone in structural work should always be laid so that pressure is at right angles to the bedding planes. The Jewish Synagogue on University Avenue in Syracuse and the central courses in Lyman Hall at Syracuse University are of this stone. (See Fig. 149.)

Kentucky. — The Bowling Green oolitic limestone has its home in Warren County. As its name implies it closely resembles the Bedford oolite already described. It however differs from the Indiana stone in one respect. It may be set with safety in any position in the walls of a building. It is of fine even texture and when freshly quarried shows a buff tint, which changes to a light gray upon exposure to the atmosphere, due to a loss of small quantities of included petroleum.

Maryland.—Two localities in Maryland are worthy of mention. The first of these lies about 15 miles north of the city of Baltimore and furnishes the Cockeysville marble. This is quarried at Cockeysville and Texas. It is an Ordovician dolomite of pure white color and even texture. Washington Monument on the banks of the Potomac contains this stone. It also appears in the columns and heavy platforms of the Capitol extensions at Washington, D. C. (See Fig. 150.)

The other locality is near Point of Rocks, Frederick County. The stone is a conglomerate which is sometimes brecciated. The pebbles are quartzose, the limestone fragments are dolomite and the whole imbedded in a calcareous ground mass. The stone is popularly known as the Potomac marble. This stone was used in the pillars in the old Hall of Representatives in Washington. (See Fig. 151.)

Massachusetts. — The marble areas of Massachusetts are confined to the Berkshire Hills in the western part of the state. Massachusetts marbles are of even texture, fine to medium grained, and shade from white to gray in color.

They are used for structural and ornamental work. The Alford quarries produce monumental stone and the Lee quarries the structural stone. From the last locality came the marble for the Capitol extensions at Washington. The stone often contains the objectionable constituent, tremolite, which falls out on long exposure and leaves the surface pitted.

Minnesota.—The calcareous building stones of Minnesota are situated in the southern part of the state near Minnesota River. Two types are advertised. The Kasota marble and the Mankato marble. They are both dolomitic and receive a polish. The interior of the Capitol building at St. Paul is

Fig. 150.—View of Beaver Dam quarry, Cockeysville, Maryland. By courtesy of the Maryland Geological Survey.

from the Minnesota dolomites. They are generally yellow or yellowish brown in color.

Missouri.—The building stones commercially catalogued as marbles in this state have a wide variety in color. The pure white crystalline marble appears to be wanting. The colors represented in Cape Giradeau, Iron and Madison Counties, are gray, yellow, pink, red, green, purple and variegated. The Monotone marble of Carthage is perhaps the best known. Many of the above varieties are limestones rather than true marbles.

Montana.—Lewis and Clark County furnishes a small amount of marble that is very compact, of dark bluish-gray color, and somewhat resembles the Italian black and gold marble from the Spezzia quarries. The stone is often traversed by wavy chrome-yellow bands.

Nevada.—According to J. F. Newberry the workable beds of limestone within the state are situated in the Tempiute Mountains in the southern part of the state. They present a
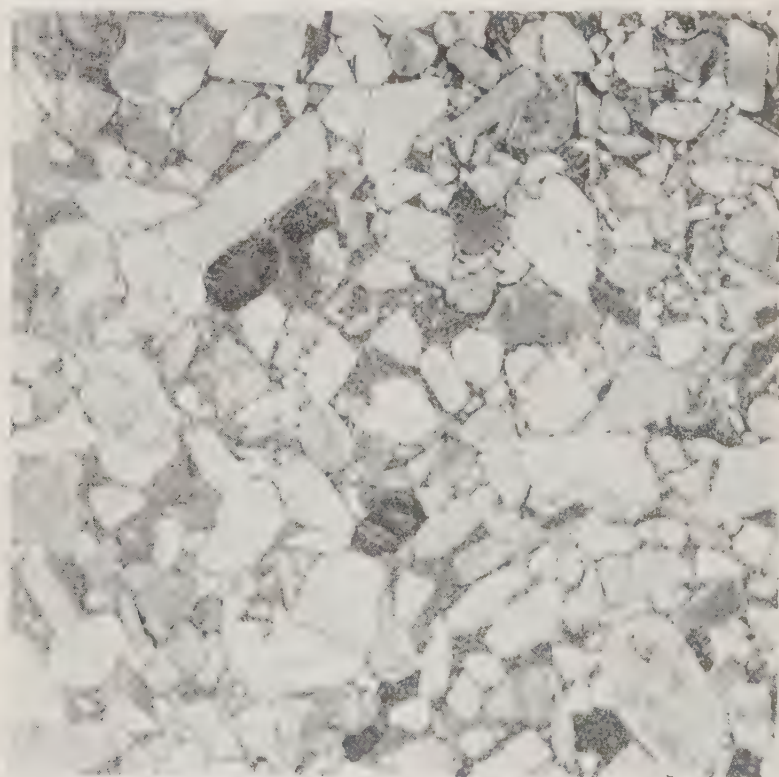
Fig. 151.—Potomac marble, Point of Rocks, Frederick County, Maryland. By courtesy of the Maryland Geological Survey.

wide variety in color and texture and are equal in beauty to the best imported marbles.

New Jersey.—The State of New Jersey produces two widely different marbles in Sussex and Warren Counties. One is known as the Kittatinny blue limestone which is used as a structural stone for the local and Pennsylvania market. The

other is known as the " Rose Crystal Marble " from its pink or rose color. These tinted crystals of calcite are associated with black mica, a green pyroxene and a black tourmaline. The stone is susceptible of a high polish and well suited for decorative interior work.

New York.—There are four distinct belts of limestone, or dolomites, or marbles, within the state.

(1) *The Hudson River Belt.*—This field lies in the south-eastern part of the state and strikes in a northerly direction. The beds are tilted to a high angle, sometimes reaching the vertical. The stone is a dolomite. The quarries of South Dover produce the finest grained marbles of Westchester County. The stone is white and is used mainly for structural work. The Tuckahoe quarries produce a pure white marble of some-what coarser texture that has been used to a considerable extent for building purposes in New York City. The Metropolitan Life building in New York is from this stone. The gray color of many buildings from this stone is said to be produced by the collection of dust upon its rough surfaces. The Pleasantville quarries produce the coarsest grained stone of the three men-tioned. The snow flake marble comes from a bed that is about 100 feet wide and snowy white in color.

The Becraft marble which is quarried on the west side of the Hudson River resembles some of the Tennessee marbles.

(2) *The Champlain Belt.*—The southernmost quarries in this district are situated at Glens Falls, a little to the south of Lake George. The stone is of dark bluish-black color and of very fine texture. In composition it is dolomitic. The stone receives a high polish equal to the famous Irish black and Belgian black marbles so often imported for decorative effect. Small hand samples when polished are of lustrous black color, while much larger samples sometimes show the presence of small white fossils. The same type of black marble is also quarried at Willsborough in Essex County. To the inexperienced these stones appear equal to the famous Irish black marbles.

A verd antique marble which in reality belongs to the ser-pentine group of decorative stone is quarried at Port Henry in the same county. The marble consists of serpentine decked with calcite and dolomite. It is used for interior work.

The Chazy limestone, which often takes a good polish, is quarried at Chazy and Plattsburg in Clinton County. The stone is often replete with fossils. The Lepanto marble is a fine grained variety of gray color and rich in white and pink colored

Fig. 152.—Hall of Languages at Syracuse University, built in 187? of Onondaga limestone.   Photo. by I. U. Doust.

fossils which afford a strong contrast. The French gray bears larger fossils than the Lepanto marble.

(3) *The St. Lawrence Valley Belt.*—Gouverneur is situated on the western side of the Adirondack Mountains in St. Lawrence County. Gouverneur marble is dolomitic in composition, of light gray color, of coarse texture and receives a high polish. It is used for monumental work, for decorative interior effect and for constructional purposes. This marble is of pre-Laurentian age.

The Lowville ("Birdseye") limestone is quarried at Lowville and along the West Canada Creek.

Fig. 153.—Niagara limestone, Rochester, New York. Whitmore, Rauber and Vicinus quarry, North Goodman Street. Base of the Lockport and upper Rochester shale. Photo. by H. L. Fairchild.

(4) *The Central Belt.*—This belt strikes in a westerly direction through the central part of the state. The Manlius limestone is of gray or dark gray color, of fine even texture and quarried extensively in the vicinity of Syracuse for underpinning and rough-faced blocks. The Onondaga limestone is of light gray color, medium texture and quarried for structural purposes. The Hall of Languages, which was the first building constructed at Syracuse University, represents this stone. A part of the Onondaga limestone is sufficiently crystalline to receive a good

polish and is therefore a marble. (See Fig. 152.) The Niagara limestone of Lockport and Rochester is of medium texture, soft gray color and quarried extensively for both structural and ornamental work. (See Figs. 153 and 154.)

The Gasport limestone, which is crinoidal, is quarried at Lockport. The Trenton limestones are quarried at Trenton Falls. Many buildings in Utica have been constructed from this stone.

North Carolina.—Marble deposits occur in this state in Cherokee, Madison, McDowell and Swain Counties. Their general strike is to the northeast. They are from fine grained to medium texture, and of white, creamy white, gray, green, pink,

Fig. 154.—Decew limestone, Rochester, New York. Rauber and Hagaman quarry, North Goodman Street, looking north. Photo. by H. L. Fairchild.

and red colors. They may be used for either structural or decorative purposes.

Ohio.—Limestones and dolomites in Ohio are quarried to some extent for structural purposes but the major part of the production finds use along the engineering lines of paving, flagging, crushed stone, manufacture of lime and as fluxing material.

Pennsylvania.—According to G. P. Merrill marble quarries were opened in Montgomery County about the time of the Revo-

lutionary War, and up to 1840 the stone was a favorite for the better class of stone buildings in and about Philadelphia. The Sarcophagi of President and Martha Washington, at Mount Vernon, represent this stone. In Chester County at Avondale a white dolomitic marble is quarried for structural work. (See Fig. 155.)

Tennessee.—More than 25 counties in this state are capable of producing marbles which present a wide variety in colors. They are grayish-white, olive-green, brownish-red, chocolate-red and pink in color. In texture they are medium to coarse grained. They are of high compression strength, weigh about

Fig. 155.—Limestone quarry at Bellefonte, Pennsylvania. Photo. by T. C. Hopkins.

180 pounds to the cubic foot, take a good polish and weather well. The finer and evenly crystalline varieties of beautiful pink color, often traversed with narrow, zigzag black bands, are widely used for wainscoting, table tops and counters. The chocolate-red variety which is variegated and fossiliferous is a very popular paneling stone. Other uses of Tennessee marble are for tombstones, monuments, switchboards and tiling. (See Figs. 156, 157, 158 and 159.)

Vermont.—According to C. H. Hitchcock the first marble quarry opened in Vermont was in Isle La Motte prior to the Revolution. H. M. Seely cites quarries opened in Dorset in 1785 by Isaac Underhill. Since the early inception of the marble industry Vermont has taken the rank of first producer. At times Vermont has furnished more than three-fourths of
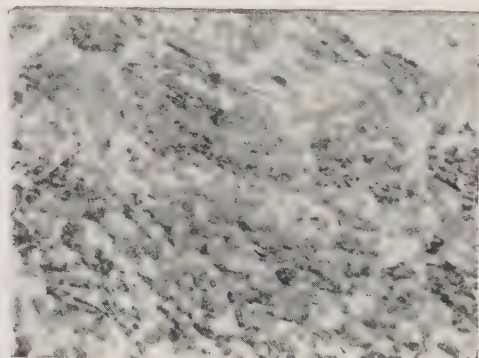
Fig. 156.—Polished slab of No. 1 Tennessee marble, Meadow, Tennessee. Photo. by C. H. Richardson.
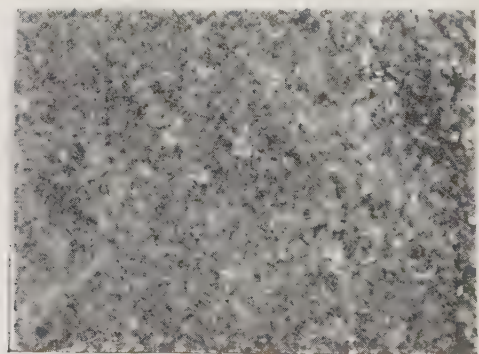
Fig. 157.—Polished sample of dark cedar marble, Meadow, Tennessee. Photo. by C. H. Richardson.

the total production of marble for building purposes in the United States and four-fifths of the monumental marbles.

DISTRIBUTION.—The marble belts of Vermont fall into six districts.

(1) The Rutland District; this belt has been by far the most important producer. (2) The Champlain District.

(3) The Plymouth District. (4) The Isle La Motte District. (5) The Washington District. (6) The Roxbury District.

THE RUTLAND BELT.—The Rutland marbles are mainly situated in Rutland County but quarries have been worked to the north in Addison County and to the south in Bennington County.

Fig. 158.—Polished slab of gray Tennessee marble, Meadow, Tennessee. Photo. by C. H. Richardson.
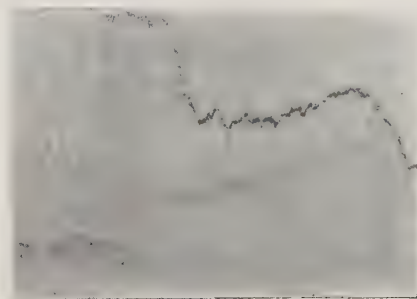
Fig. 159.—Polished slab of champion pink marble, Meadow, Tennessee. Photo. by C. H. Richardson.

The beds of marble themselves vary widely in thickness, from 6 feet to 100 feet or even more. In texture they are usually fine grained. In color these marbles are in part a pure white, sometimes gray, banded, variegated, deep bluish black and occasionally greenish.

Dorset Mountain.—On practically all sides of this mountain beds of good marbles have been quarried. The quarries of J. K. Freedly and Sons are situated on the east side of the mountain.

The quarries are about 1,000 feet above the valley and capped
by about 500 feet of slate. The method of quarrying is in part
open cut work and in part a room and pillar method. In the
latter case large pillars of marble are left to support the roof
of slate that overlies the marble. Most of the product of the
Freedly quarries is shipped to Philadelphia. On the southeast
side of the same mountain are found the so-called "blue ledge

Fig. 160.—View of marble quarry at West Rutland, Vermont, show-
ing dip of the marble beds. Photo. by C. H. Richardson.

quarries." It is a very handsome bluish marble that is not ex-
tensively worked. The Edison quarries are situated on the south-
west side of Dorset Mountain. These quarries like some of the
marble quarries of Brandon and Pittsford show the peculiarity
of the beds when traversed with the channelling and gadding
machines of springing up from the floor of the quarry and
tightly holding various tools in the work.

The quarries of the Dorset Mountain Marble Company are situated on the west side of Dorset Mountain. Borings have here revealed the marble beds several hundred feet in thickness. The marble is largely variegated. Many abandoned quarries are found all around the mountain.

West Rutland.—About 25 quarries in the neighborhood of West Rutland are owned and operated by the Vermont Marble Company, which is the largest marble company in the world.
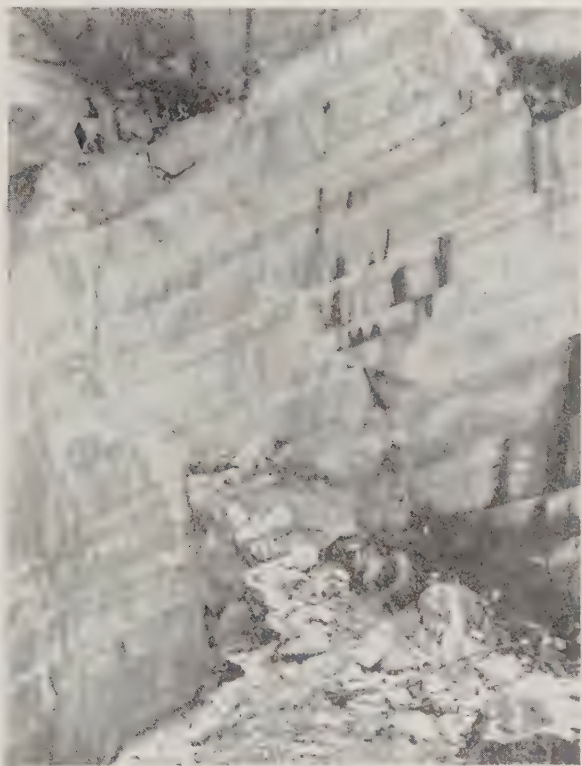
Fig. 161.—Interior view of marble quarry, West Rutland, Vermont, showing dip of the marble benches.   Photo. by C. H. Richardson.

The marble beds lie on both sides of a ridge that stretches from the southern boundary of Rutland northward to the northern boundary of Middlebury. The beds vary from 100 to 200 feet in thickness, although important beds are often much thinner. The more important deposits lie on the western side of the ridge where the angle of dip varies from 45° to 80° to the east. (See Figs. 160 and 161.)

Fig. 162.— Sutherland Falls quarry, Proctor, Vermont   By courtesy of the Vermont Marble Company.

"Covered Quarry"—This quarry is 300 feet deep with two tunnels some 250 feet in length running under the cliffs. The beds are so free from joint planes that blocks of any size desired are obtainable. According to G. H. Perkins the texture is quite uniform throughout. The beds vary widely in color. Some layers produce a pure white statuary marble which G. P. Merrill says lacks the mellow waxy luster of its Italian prototype. How-

Fig. 163.—Marble quarry, Proctor, Vermont. Photo. by C. H. Richardson.

ever, the author has seen two statuettes side by side, one cut from the Rutland statuary marble and the other from the Italian, which practically every visitor declared came from the same quarry. Other beds are gray, yellow, light brown, olive, green, blue and variegated. In one quarry there are 15 beds that vary in thickness from two to ten feet and vary widely in texture, color and value.

The Eighteenth Annual Report of the United States Geological Survey furnishes the following data on a geological section of the West Rutland quarries.

White marble (blue marble top) . . . . .20 feet
Green striped . . . . .2 feet
White statuary . . . . .5-6 feet
Striped ornamental . . . . .2-6 feet
White statuary . . . . .3-6 feet
Layer partly green and partly white . . . . .4 feet
Green and "Brocadillo" . . . . .2¼-3 feet
Crinkly siliceous layer, half light, half dark . . . . .2-3 feet
Light and mottled . . . . .4-6 feet
Green striped . . . . .6 inches
White . . . . .2½ inches
Half dark green and half white . . . . .3-6 inches
Italian blue . . . . .15-20 inches
Mottled limestone . . . .

Proctor.—The town of Proctor formerly known as Sutherland Falls, is another important marble producer. The quarry floor covers about three acres while the marble walls rise over 200 feet above the floor. On the floor the beds lie in nearly a horizontal position with some evidence of an anticlinal arrangement. The colors range from nearly white to dark gray. (See Figs. 162 and 163.)

"Mourning Vein."—The marble of this quarry is of very fine texture with numerous wavy and almost black markings. H. M. Seely says "That it would be interesting to know the origin of these mourning marbles, in which the white and black are so conspicuously mingled. The material giving the black appearance is undoubtedly carbon, and probably in character approaching the graphite which marks the coarsely crystalline limestones of the Adirondack region. When freely exposed to a high heat the dark color disappears, leaving a white line. The conjecture might be ventured that the rock was originally of different chemical composition in the different parts. In the white the oxidation of the carbon was complete during metamorphism, while in the dark the oxidation was interfered with. A second theory would be that during the metamorphism the particles of carbon moved together and became aggregated as in the Adirondack marble." The first theory is supported by an actual difference in chemical composition as the dark portions carry insoluble siliceous minerals that are absent in the white portions.

Pittsford.—There are three marble beds in Pittsford, which

strike north and south, and vary from 200 to 400 feet in width. The marbles vary from white to a dark blue. The quarries now in operation produce the latter variety.

Brandon.—About half a mile south of Brandon station are situated the long narrow beds of Brandon Italian marble. The beds are about 8 feet thick and channelling machines are used to cut the stone. The Bardillo quarries are situated about two and one-half miles southwest of Brandon station. These quarries produce a unique marble that is strongly marked with narrow veins that traverse the stone in zigzag lines with some regularity. The colors shade from light to dark gray. (See Fig. 164.)

Age.—The age of the marbles of this most important marble belt of America is Ordovician. Some of the lower beds of the
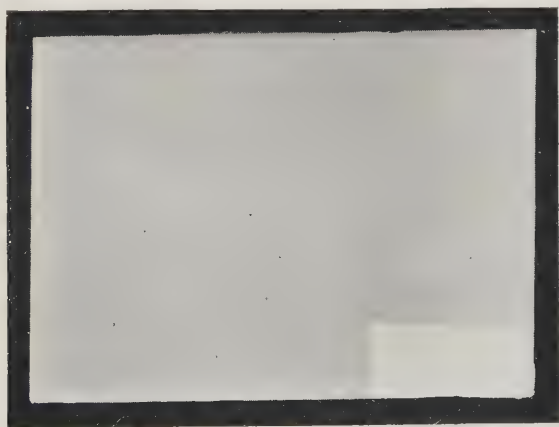
Fig. 164.—Polished slab of Italian marble, Brandon, Vermont. Photo. by C. H. Richardson.

West Rutland quarries may yet be proven older than the Chazy division of the Ordovician and the uppermost beds may be younger than the Chazy. In the main they are Chazy. The dolomite beds are probably of Cambrian age.

The Vermont Marble Company, which operates the great majority of the quarries in the Eolian or Rutland district has kindly furnished the following list of varieties with their characteristic trade names. The list includes seven marbles from the Winooski district and one from the Roxbury district.

Albertson, extra dark.—This marble has long been known as the Esperanza. It is one of the darkest of the Vermont marbles.

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The ground mass is thickly covered by darker veins in many cases more or less confluent. The quarries are at West Rutland.

American Pavonazzo.—The ground is a delicately shaded creamy white or light yellow. The stone is veined with many shades varying from light to almost black. The quarries are at West Rutland.

American Yellow Pavonazzo.—The ground is a light yellow or yellow salmon. The green clouds are very irregular and sinuous. The contrast is strong. The quarries are at West Rutland. (See Fig. 165.)
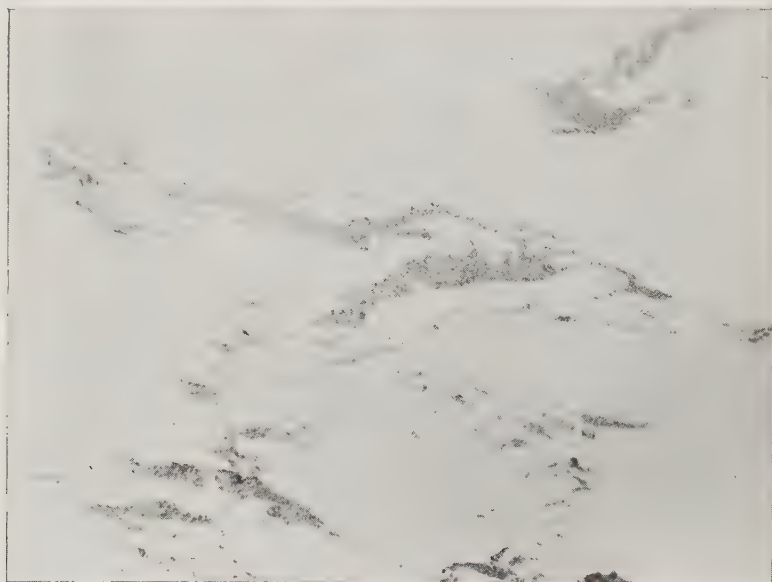
Fig. 165.—Polished slab of American pavonazzo marble, West Rutland, Vermont. Photo. by C. H. Richardson.

Avenatto.—This marble has a very light ground with many light brown veins fading to a smoke brown. The veins are very irregular and extend in different directions. The stone is quarried at Florence.

Best Light Cloud Rutland.—At a distance this stone appears white. It contains a very small amount of coloring matter. The stone is quarried at West Rutland.

Brandon Italian.—As the name implies, this marble somewhat closely resembles the ordinary imported Italian marble. The

ground is white but more or less thickly veined with black or bluish lines, or spots, or blotches. The quarries are at Brandon. (See Fig. 166.)

Brocadillo.—This is a green marble. The ground is a greenish white in which there are veins and clouds of varying shades of green. The quarries are at West Rutland.

Cipollino.—The general color of this marble is a slightly yellowish green. Three varieties are recognized, light, medium and dark. The stone is obtained from the Westland quarry at West Rutland.
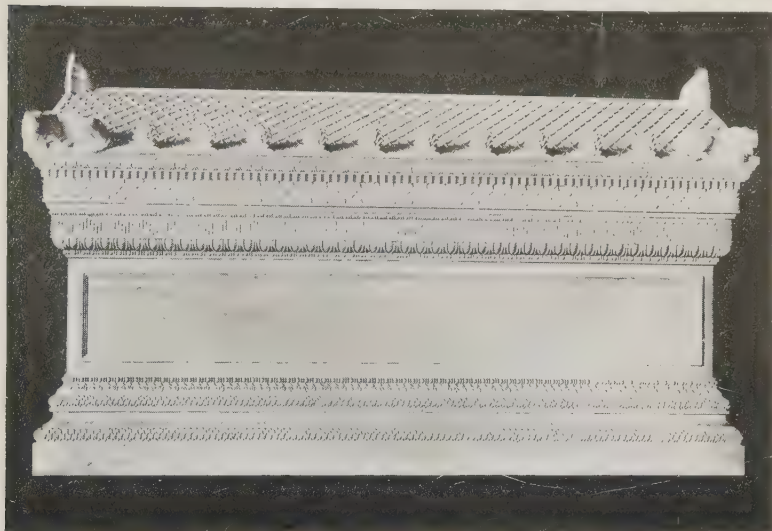
Fig. 166.—Sarcophagus constructed by the Vermont Marble Company. By courtesy of the Vermont Marble Company.

Dark Florence.—The bluish ground of this marble is abundantly veined by regular and fairly straight lines, or bands, which are often confluent. The quarries are at Florence.

Dark Vein True Blue.—This stone is one of the darkest of the blue marbles but lighter than the Albertson. The quarries are at West Rutland. (See Fig. 167.)

Dorset Green Bed.—The ground of this marble is white or greenish with streaks and bands of varying shades of green. The quarries are at Dorset.

Dorset A.—The ground of this marble is almost white with a slight yellowish tint clouded by faint greenish or olive patches. The quarries are at Dorset.

Dorset B.—The ground is nearly white with irregular bands of creamy white alternating or blending with streaks or clouds of greenish shades. The quarries are at Dorset.

Dove Blue Rutland.—The stone is of gray-blue color. Sometimes it is of Quaker drab color. This bed carries the well known fossil, Maclurea magna, which fixes definitely the age of the formation. The quarries are at West Rutland.

Esperanza.—The ground of this stone is a dark bluish gray and through this there are lines and veins of still darker shades

Fig. 167.—Polished slab of true blue marble, West Rutland, Vermont, showing faults. By courtesy of the Vermont Marble Company.

of the same color and others are nearly black. The quarries are at West Rutland.

Fisk Black.—Some of the layers of this marble are so dark a grade that when they are polished they appear a jet black. The quarries are on Isle la Motte.

Florentine Blue.—This marble is of medium tone, lighter than most of the blue marbles and darker than others. When polished it is of dark dove shade. The quarries are at Pittsford.

Fig. 168.—American eagle cut from Vermont white marble. By courtesy of the Vermont Marble Company.

Jasper.—All of the varieties are red or reddish in color with a good deal of white calcite and quartz. The jasper marbles receive a high polish and are very lasting. The quarries are at Swanton.

Light Rutland Italian.—This marble has large areas of fairly white color with a few clouds shading out into the white ground. It has much the appearance of the common Italian marbles. The quarries are at West Rutland. (See Fig. 168.)

Light Sutherland Falls.—This marble is nearly pure white but in the ground there are distributed numerous and quite distinct dark bluish veins. The quarries are at Proctor.

Fig. 169.—Polished slab of listavena marble, West Rutland, Vermont. Photo. by C. H. Richardson.

Listavena.—This is a veined marble and one of the best for interior work. The white bands alternate with shades of green or olive. The quarries are at West Rutland. See Fig. 169.)

Levido.—The ground of this marble is a light bluish gray with numerous veins, lines and blotches of a much darker hue. The quarries are at West Rutland. (See Fig. 170.)

Lyonnaise.—The red color in this marble is darker than that in the Jasper. The veins are dark and lighter shades of red. Some of the veins are white. The quarries are at Swanton. (See Fig. 171.)

Marine Venoso.—The confluent veins and bands of this marble form bold masses of shades of green, darker and lighter, with broad wavy bands of white and sometimes pink colors. The stone closely resembles some of the Georgia marbles. The quarries are at West Rutland.

Moss Vein.—In this marble the two colors, a dark gray and a white, are peculiarly intermingled. The darker shades predominate. The quarries are at Dorset.

Olive.—As the name implies the ground of this marble is a
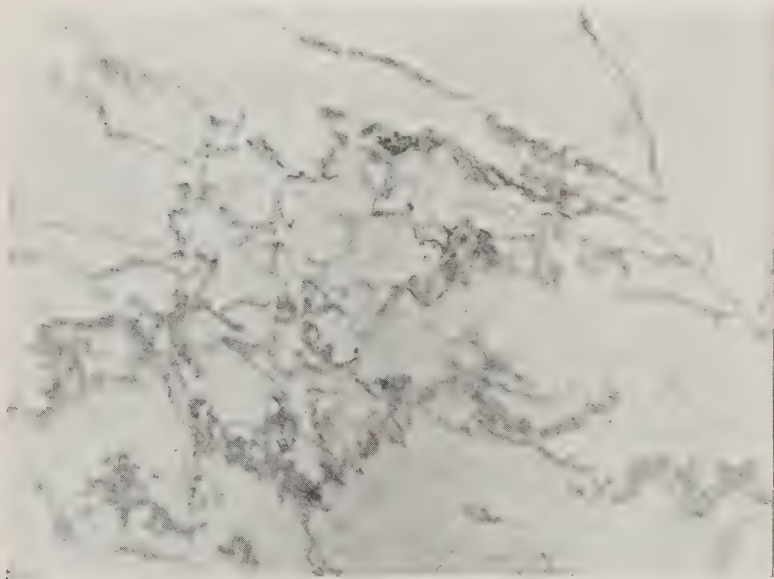
Fig. 170.—Polished slab of livido marble, West Rutland, Vermont. Photo. by C. H. Richardson.

drab or olive drab. In many pieces of the marble there are varying shades of red, mostly quite light. The quarries are at Swanton.

Oriental.—This peculiar marble presents an intermingling of red, brownish red, purplish red and clear white colors. It is one of the finest and most beautiful of the Vermont marbles. The quarries are at Malletts Bay. (See Fig. 172.)

Pink Listavena.—This marble is delicately shaded in the exquisite pink ground and the equally shaded greenish veins and bands. The quarries are at West Rutland.

Riverside.—This is a light pearl white variety. There are some

bluish veins, spots and bands. The usual waste found in most
quarry openings is absent here. The quarries are between
Proctor and Rutland.

Royal Red.—This stone is for the most part a deep Indian red,
with a blending of dark and rich shades. The quarries are at
Swanton. (See Fig. 173.)

Rubio.—This marble is a light salmon pink with softly shaded
light green or greenish veins. The quarries are at West Rutland.

Rutland Building.—This is one of the more common white
marbles used for building purposes. The quarries are at West
Rutland.
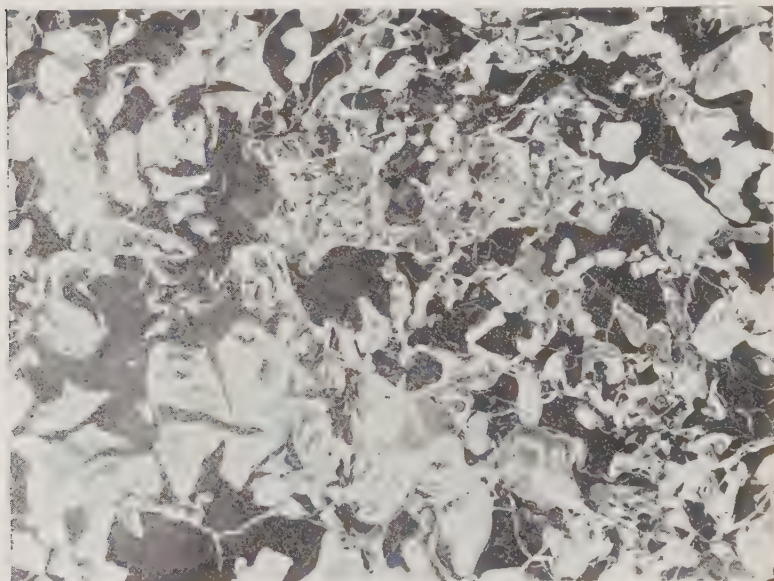
Fig. 171.—Polished slab of lyonnaise marble, Swanton, Vermont.
Photo. by C. H. Richardson.

Special Rutland Italian.—This stone is less clouded and more
distinctly veined than the Light Rutland Italian marble. The
quarries are at West Rutland.

Standard Green.—The green shades are the most prominent
with smaller areas of white, pink and very light bluish shades.
The quarries are at West Rutland.

Swanton Dove.—This marble is a drab or bluish gray varied
by pure veins, white spots and blotches. The quarries are at
Swanton.

True Blue.—This marble has a medium ground which is crossed by dark to black bedding planes. The quarries are at West Rutland.

Verd Antique.—This stone is a serpentine. It will be described more fully in Chapter VII. It is a marble only in a commercial sense. The rock is of dark purplish or greenish color in the mass and plentifully veined with dolomite. The quarries are at Roxbury. (See Fig. 174.)

Verdoso.—In this marble the shades vary from apple green to dark and even black. The quarries are at West Rutland. (See Fig. 173.)
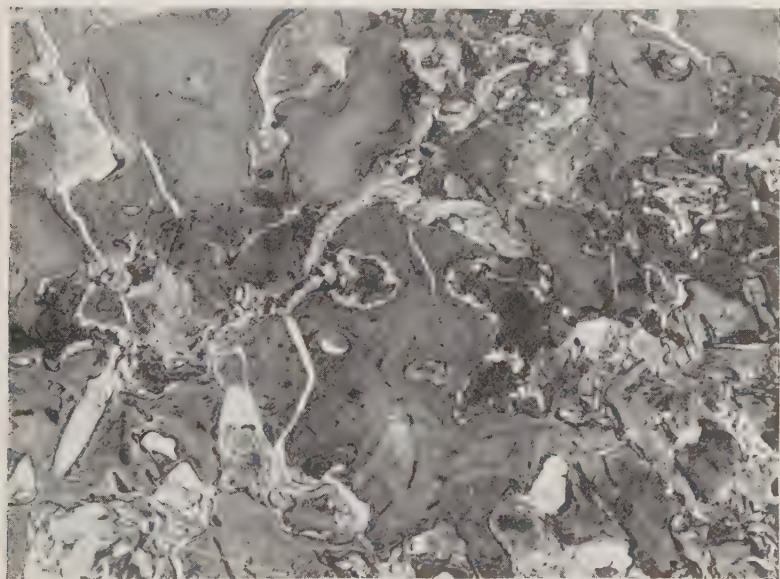
Fig. 172.—Polished slab of oriental marble, Malletts Bay, Vermont. Photo. by C. H. Richardson.

Vert de Mer.—The general tone of this marble is light with a few small and dark veins. The peculiar mottled effect causes the surface of the stone to appear covered with slightly rippling water. The quarries are at West Rutland.

Westland Cream.—This marble was formerly called Rosaro. The most common tone is a light yellow with more or less of a salmon tone. The quarries are at West Rutland.

THE WINOOSKI DISTRICT.—This belt of calcareous rocks extends southward along the eastern shore of Lake Champlain

from the International boundary on the north to Shoreham. The belt is narrow and practically parallel with the Champlain coast line. The marbles are commercially known as the Champlain marbles. The thickness of these beds will be seen in the geological section cited a little later in this work.

Origin.—The origin of these unique marbles differs so widely from the true metamorphic marbles of West Rutland that it deserves special mention. They represent beds of siliceous sediments, highly calcareous, which are now substantially in the same condition as when they were originally deposited. They have never suffered the characteristic metamorphism of the true marbles. In this respect they differ widely from all other marbles of the state save the marbles of Isle La Motte which in reality are limestones.

Fig. 173.—Polished slab of royal red marble, Swanton, Vermont. Photo. by C. H. Richardson.

Color.—The color is chiefly some shade of red. Light red, dark red, yellowish red, pink, reddish brown, olive, light green and even white marbles are encountered. In texture these marbles are fine grained to medium and very hard.

Composition.—In composition these marbles may be classified as siliceous dolomites. The calcium carbonate ranges from 30 to 40 per cent; the magnesium carbonate ranges approximately the same; the silica from 10 per cent upwards, while iron and alumina are present in smaller proportions. Specimens taken for analysis from different places in the same quarry, or from different quarries would yield different results. The old red sandrock, of which these beds form a part, consists of sand held together by a calcareous and ferruginous cement. Some of the

layers appear quite different from the old red sandrock, while others pass into it by insensible gradations. The marble beds themselves appear just north of the city of Burlington and extend in a northerly direction through St. Albans to Swanton.

The Barney Marble Company, now a part of the Vermont Marble Company, operates the great majority of the quarries in this district. More than 30 varieties are produced. The stone is far better suited for decorative interior work than it is for monumental or structural purposes, as the stone exposed to the weather, fades to a somewhat limited extent. The stone when protected from the inclemency of the weather is always perma-
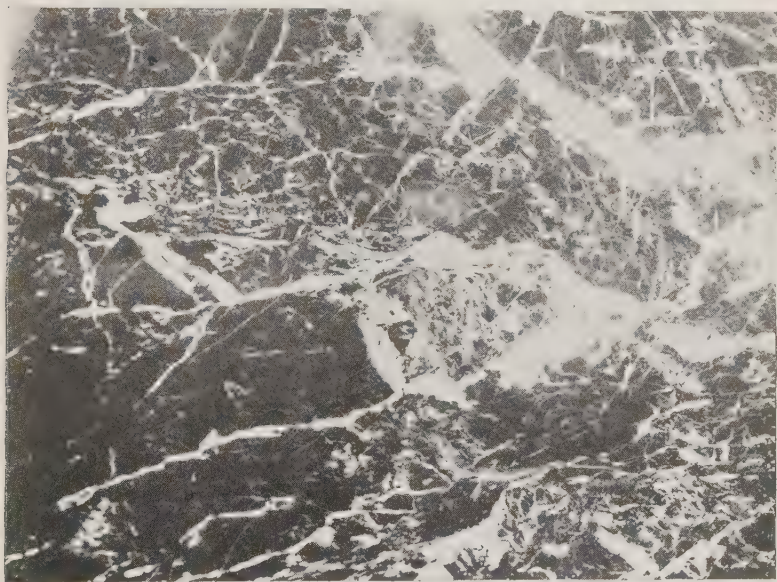
Fig. 174.—Polished slab of Verd antique marble, Roxbury, Vermont. Photo. by C. H. Richardson.

nent in color. This stone can be seen in the wainscoting in the corridors in the Capitol at Albany, N. Y., and in the Astor library in New York City.

The possibility of the large number of varieties obtainable in this belt is explained by the fact that the upper and lower surfaces vary greatly in the same slab. Variations also are produced by cutting the stone at one time parallel with the planes of sedimentation and at another time transverse to these planes. In fact, any deviation in cutting gives different results in color or varieties of color.

A breccia marble containing fragments of broken material ranging in size from a small fraction of an inch to many inches, enclosed in a dark red paste, furnishes one of the handsomest varieties. The angularity of some fragments is perfect, for the material appears to have been one larger piece when first held in the paste and subsequently broken. In such instances the fractured parts correspond perfectly with each other. In other cases the structure conforms to that of an inter-formational conglomerate. Here the angularity of the fragments is lost for the material was well worked before cementation became complete.

The following geological section (reading down) was worked out by W. E. Logan and modified by G. H. Perkins.
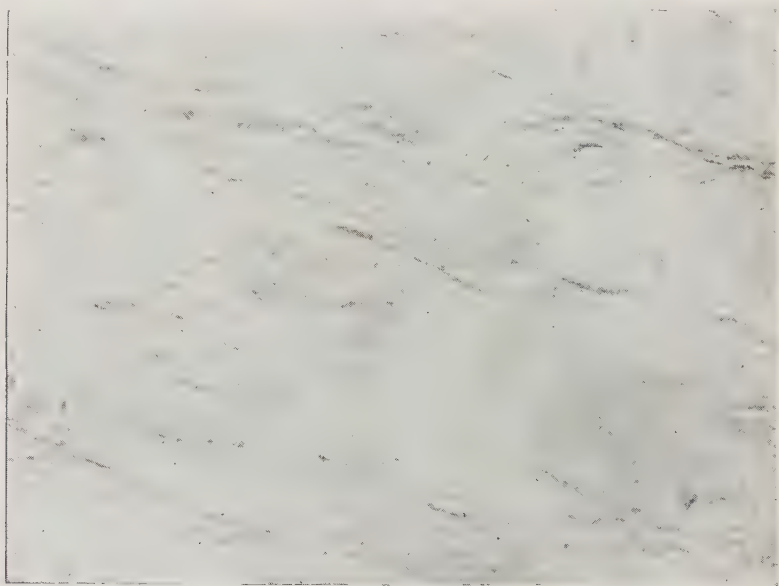
Fig. 175.—Polished slab of Verdosa marble, West Rutland, Vermont. Photo. by C. H. Richardson.

White and red dolomite (Winooski marble) with sandy
    layers; some of the strata are mottled, rose red and
    white, and a few are brick red or Indian red....... 370 feet

Gray argillaceous limestone, partly magnesian........ 110 feet

Buff sandy dolomite............................ 40 feet

Dark gray and bluish black slate, partly magnesian,
    with thin bands of sandy dolomite................ 130 feet

Bands of bluish mottled dolomite, mixed with patches
of gray pure limestone and gray dolomite and bands
of gray micaceous flagstone...................... 60 feet
Light gray more or less dolomitic sandstones, some of
which are fine grained, others are fine conglomerates.
These are interstratified with bands of a white sand-
stone .... 630 feet
Bluish thin bedded argillaceous flagstones and slates... 60 feet
Bluish and yellow mottled dolomite................ 120 feet
Yellowish and yellowish gray sandy dolomite......... 600 feet
To which Logan adds in Canada
Buff and whitish sandy dolomite, holding a great
amount of black and gray chert in irregular frag-
ments of various sizes up to a foot in length and six
inches wide (thickness estimated)................ 790 feet

2910 feet
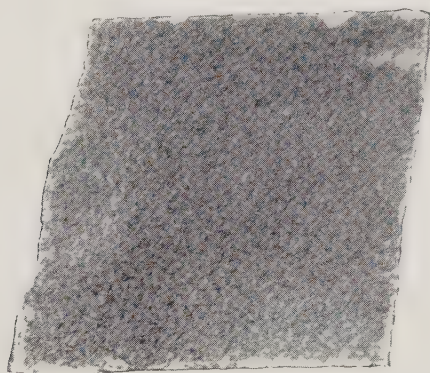
Fig. 176.—Polished slab of quartzose marble from R. F. Richardson
quarry, Washington, Vermont. Photo. by C. H. Richardson.

Age.—The Champlain marbles are older than those of West
Rutland. The red sandrock which carries the beds of widely
variegated marbles is specifically recognized as Lower Cambrian,
from the presence of its fossil content.

THE PLYMOUTH BELT.—The highly variegated marble of
Plymouth covers a large part of the township bearing that name.
The beds are about 250 feet above Plymouth Pond and some
six miles from the railroad station at Ludlow. The marble
beds are associated with talcose schists and strike north 10
degrees west with dip 60 degrees to the east. T. N. Dale
considers these marbles of Cambrian age.

Composition.—The marble is practically a pure dolomite, as will be shown in the analyses of marbles given for reference. It is of fine grain, even texture, of white and variegated colors, often banded, splits well in all directions and strongly resists atmospheric influences. The distance from the railroad does not permit this decorative marble to actively compete with the Rutland and Champlain marbles.

ISLE LA MOTTE BELT.—On Isle La Motte in Lake Champlain there are extensive beds of limestone, some of which are susceptible of a high polish. They are of fine even texture and in color

Fig. 177.—Blocks of quartzose marble showing character of freshly broken surface. The two larger pieces are Washington marble and the smaller one is Waits River marble. Photo. by C. H. Richardson.

gray to black. The black varieties become at times mottled in appearance due to numerous small fossil fragments. The black color is due to the presence of uncombined carbon. Many samples of this variety take a polish equal to that of the famous Irish and Belgian black marbles. The beds lie in a nearly horizontal position and vary from two to ten feet in thickness. The entire limestone beds represent about thirty feet of rocks. The stone from the Goodsell and Fleury quarries is mainly gray in color and placed on the markets as "French gray" marble. The

stone from the Fisk quarries is mainly black and sold as "Fisk black" marble. The stone is in a large demand for bridge piers, foundation work and decorative interior work. These limestones represent a deep stillwater deposit that since deposition has been but slightly disturbed.

Age.—The age of the gray limestones is lower Chazy and of

Fig. 178.—Monument cut from Washington marble, Washington, Vermont, showing marked contrast between the hammered and polished surfaces. Photo. by C. H. Richardson.

the black middle Chazy, which places them both in the Chazy division of the Ordovician.

THE WASHINGTON DISTRICT.—This district is named from the township of Washington in Orange County, where several quarries have been opened and abandoned. The beds here lie in a nearly horizontal position with a pitch of three to five degrees to the north and a strike of north 20 degrees west. Some of the

sheets are from eight to ten feet in thickness and from ten to one hundred feet in length. The stone hammers white and the polished letters are legible to a greater distance than the letters on any known granite. (The author has personally made over 1,500 of these tests.) The stone cuts to a fine edge and takes a high polish. The polished surface, which is uniformly dark gray, is permanent when not exposed to the corrosive agents of the atmosphere. The stone is used for underpinning and monumental work. (See Figs. 176, 177 and 178.)

Waits River.—The marble here instead of being uniformly dark gray like most of the Washington marble, is plicated or beautifully banded and mottled in appearance. The stone has been quarried and used to some extent for monumental work.
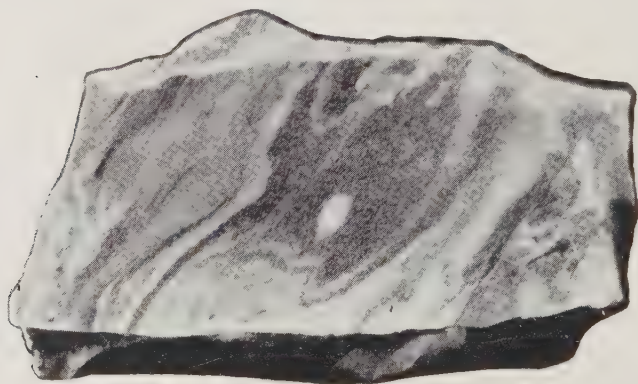
Fig. 179.—Polished block of Waits River marble, Waits River, Vermont, from H. C. Richardson quarry. The sample was polished in 1893 and photographed in 1916. Photo. by C. H. Richardson.

It is better suited for decorative interior work than for structural purposes. (See Fig. 179.)

The belt of limestone in which these two marbles fall stretches in a northeasterly direction across the entire state and reaches a maximum width of over thirty miles. Some beds are known to be over 200 feet in thickness.

Quarries of these quartzose marbles can be opened in Caledonia, Orange, Orleans, Washington and Windsor Counties. These deposits are best catalogued as marble reserves. (See Fig. 180.)

Origin.—These limestones represent a deposition of siliceous sediments that were largely calcareous. They carry from 25 to

35 per cent of silica, from 50 to 60 per cent of calcium carbonate and less than 5 per cent of magnesium carbonate. The beds of limestone pass sometimes by insensible gradations into a calcareous sandstone.

Age.—The age of these marbles, based upon paleontological evidence, is Ordovician.

Rhodonite.—This rock occurs at Waits River, Vermont, in masses of sufficient size to be of commercial significance. It is susceptible of a high polish. It is a silicate of manganese, and may be catalogued as a minor decorative stone. (See Fig. 181.)

THE ROXBURY DISTRICT.—This little district is situated on the height of land along the Central Vermont railroad between Montpelier, the Capital of the state, and White River Junction.
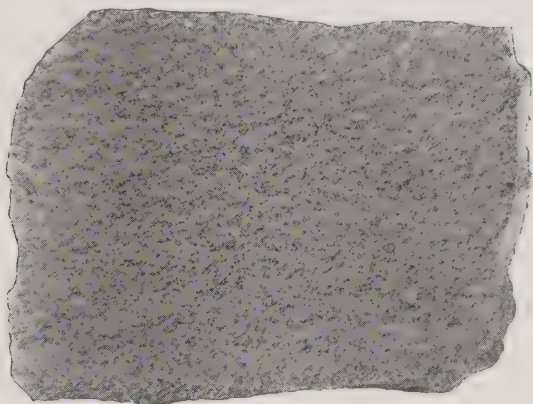
Fig. 180.—Thin slab of unpolished quartzose marble from St. Johnsbury, Vermont. Photo. by C. H. Richardson.

The place where the quarries were opened by the American Verde Antique Company is about eighty rods from the Roxbury Station.

These properties were worked for many years by the Barney Marble Company of Swanton, Vermont. They are now owned and operated by the Vermont Marble Company of Proctor, Vt. The Barney Marble Company, however, is permitted to retain its name.

Mineral Composition.—This stone, strictly speaking, is not a marble but a serpentine. It consists of a mixture of serpentine, talc and dolomite. Chrysotile, antigorite and magnetite are associated minerals. The serpentine of the Roxbury area is overlaid

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by green chlorite schists. The serpentine itself is one of the most beautiful of all known rocks for decorative interior work. It receives a high polish which is permanent indoors but the stone fades somewhat on exposure to the atmosphere. The main color is a deep green traversed by a network of white veins, and often patches of black. It is unquestionably one of the most desirable of all verd antique marbles. (See Figs. 182 and 183.)

For a fuller description of this serpentine belt see Vermont in Chapter VII.

Fig. 181.—Polished block of rhodonite, Waits River, Vermont. Photo. by C. H. Richardson.

A larger amount of space than would normally be allowed has been accorded to the marbles of Vermont because of the rank the State enjoys as a marble producer.

Virginia.—The limestones and marbles of this state occupy a considerable area to the west of the Blue Ridge Mountains. They are of Cambro-Ordovician age. G. P. Merrill recognizes the following varieties: (1) New Market and Woodstock marble, which is somewhat coarse textured and sun-

colored. (2) New Market also produces a coarse grained, mottled and bluish marble. (3) Buchanan marble, which is fine grained and gray. (4) Lexington marble, which is fine grained and pure white. (5) Giles County marble, which is fine grained and red. (6) Blacksburg marble, which is fine grained and black. (7) Craigsville limestone, which is pink,

Fig. 182.—Unpolished block of Verd antique marble, Roxbury, Vermont. Dimensions 6 by 10 feet. Photo. by C. H. Richardson.

spotted, and receives a good polish. (8) Tye River marble, which is pure white in color and suited for statuary uses. (9) Goose Creek marbles, which are fine grained, white, pink and verd antique. (10) Luray marbles, which are obtained from the stalagmites and stalactites of the Luray Caverns. Some of these onyx marbles are susceptible of a fine polish.

FOREIGN LIMESTONES AND MARBLES

Africa.—According to G. P. Merrill the collection of marbles in the National Museum from Africa contains a large number of handsome marbles of smooth surface and high polish designated in the marts of trade under the following names: jaune, antique doré, pavonazzo rosso, jaune chiaro ondate, jaune rosé, rose clair, breche sanguin, and jaspe rouge.

Fig. 183.—Old quarry in verd antique marble, Roxbury, Vermont, showing bench marks produced in quarrying the stone. Photo. by C. H. Richardson.

Austria.—According to J. A. Howe crystalline limestones and marbles of great beauty and value for both structural and ornamental work occur in Galicia, Hungary, Silesia and Tyrol.

Belgium.—The Belgian marbles are white, gray, blue, black and veined. The Belgian black marble is extremely fine

grained like the Irish black and receives a fine polish. Five black marbles whose polished surfaces closely resemble each other and which are substituted somewhat for each other for decorative interior work are the Irish black, the Glens Falls black, the Belgian black, the Italian black and the Isle La Motte black. (See Fig. 184.)

Bermuda.—According to W. N. Rice most of the homes of Bermuda are built of a soft friable shell and coralline limestone that is a pure white. The stone is whitewashed to preserve it, even in the mild climate of Bermuda. It would not withstand the action of frost in the northern portions of the United States. The Bermuda limestone is in part eolian—a calc-sand dune deposit.
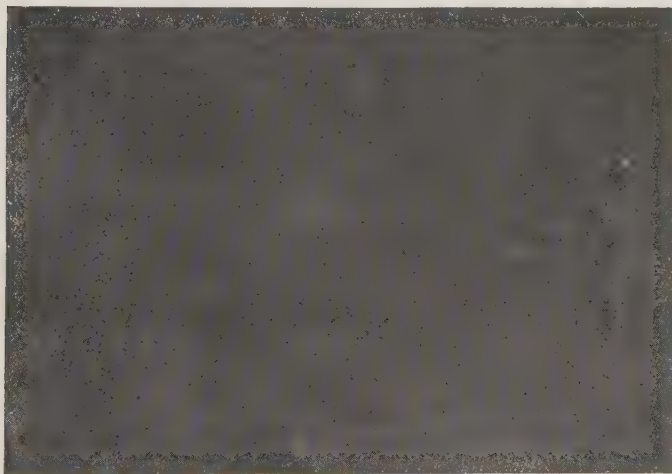
Fig. 184.—Polished slab of Belgian black marble. Photo. by C. H. Richardson.

British Columbia.—The marbles of British Columbia are well suited for structural and ornamental work. They are white, gray, pink mottled and variegated. They are especially abundant on Taxada and Vancouver Islands.

England.—According to J. A. Howe the calcareous formations of England occur in the Devonian, Lower Carboniferous, Jurassic and Chalk formations. The largest and best quarries in the Devonian rocks are found in South Devon. The prevailing colors are white, blue gray, dark gray and pinkish gray. They are well suited for constructional work but not

for piers and breakwaters. The Carboniferous limestones occur in Derbyshire. The stone is fine grained, even textured, of cream color and weathers well. It is used for monumental work, landings, steps, curbs and paving blocks.

The landscape marble or forest marble that has furnished so many fine museum samples from the southwestern part of England, is an irregular, argillaceous and calcareous deposit that bears peculiar dendritic markings, from which it receives its name. The stone is of fine grain, even texture, drab and bluish colors and used for walling, flooring, pitching and farm buildings. The quarries are located in Gloucestershire, Oxfordshire and Wilts. (See Fig. 185.)
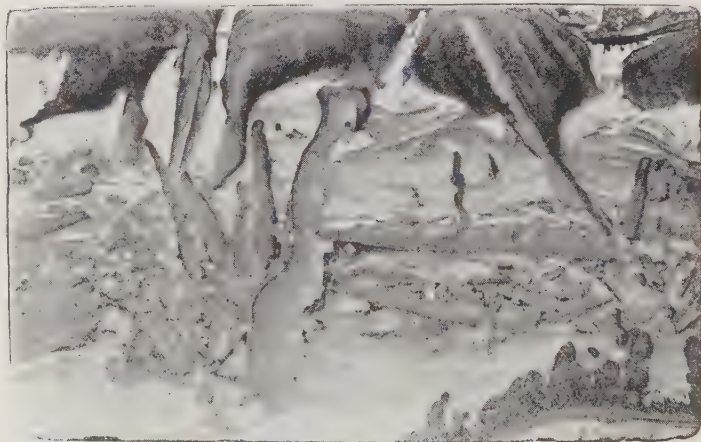
Fig. 185.—Sawn slab of landscape marble, England. Photo. by C. H. Richardson.

Fluorite.—This mineral occurs in masses of sufficient dimensions in Derbyshire, England, to be of considerable economic importance as a decorative stone. It is a marble only in a commercial sense. (See Fig. 186.)

France.—The Griotto, or French Red marble, of the French Pyrenees, is one of the handsomest of all known marbles. It is of fine grain, even texture, and brilliant red color. It receives a good polish. Small polished samples often found in drug stores are homogeneous, but the material used in the decorations of the Capitol building at Albany, N. Y., is full of flaws.

The Languedoc marble, or French Red, is another brilliant scarlet colored marble that has been quarried at Montagne Noire since the sixteenth century. (See Fig. 187.)

The Caen stone is a soft, fine grained stone, light in color, and particularly well suited for carved work. It received its name from Caen, in Normandy, where the most important quarries are located. These quarries are supposed to have been opened soon after the Norman conquest. The famous Cathedral of Canterbury and Westminster Abbey are from this stone.

Fig. 186.—Polished slab of fluorite, Derbyshire, England. Photo. by C. H. Richardson.

The Brocatelle marble, which is used so widely for mantels and decorative interior work, is very fine and compact in texture, and of light yellow color, traversed by irregular veins and blotches of dull red color. Its home is in Jura, in eastern France.

Germany.—Nassau, Germany, produces according to G. P. Merrill two beautiful marbles. The Formosa, which is dark gray, and white, mottled and blotched with red. The Bougard,

which is lighter in color and whose tints are more obscure. The Solenhofen lithographic limestone is of drab color.

Ireland.—The Carboniferous limestones and marbles cover nearly all of the center of the island. The Brachernagh marble is a pale blue; the Foynes marble, gray and blue; the Gillogue marble, blue-black; the Limerick marble, bluish black; the Lexlip marble, black; the Skerries marble, gray. It is the Lexlip marble that receives the trade name "Irish black," and to which allusion has already been made.

Italy.—The quarries of the Apennines in northern Italy, near Carrara, Massa and Serravezza, furnish marbles in beauty and variety equal to any marbles of the world. Many of these marbles are largely imported for statuary purposes and decorative interior work. The decorative marble in the new build-
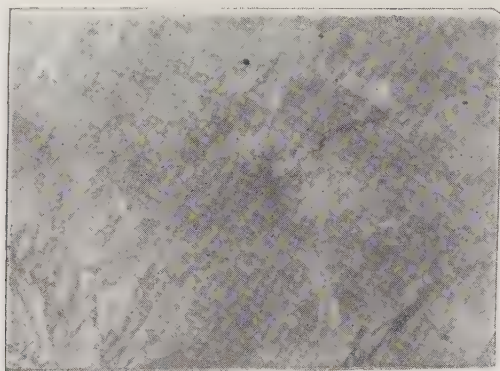
Fig. 187.—Polished slab of French red marble, Montagne Noire, France. Photo. by C. H. Richardson.

ing of the Syracuse Trust Company came from near the border line between Italy and France. It is called the Travernelle Fleuri. (See Fig. 188.)

G. P. Merrill, in his "Geology of Building Stones," cites the following varieties: (1) White statuary marble. A fine grained saccharoidal, pure white marble, without specks or flaws. (2) Ordinary white marble. This is a white variety that is sometimes faintly bluish and veined. It is largely imported for monumental work. (3) The Bardiglio is a white marble often blotched with darker hues, and traversed with a network of faintly bluish lines. (4) The Levante marble is a breccia which is composed of irregular whitish and red fragments embedded in a reddish paste. (5) The Sienna marbles

Fig. 188.—Polished slab of travernelle fleuri marble from near the border between Italy and France. Photo. by C. H. Richardson.
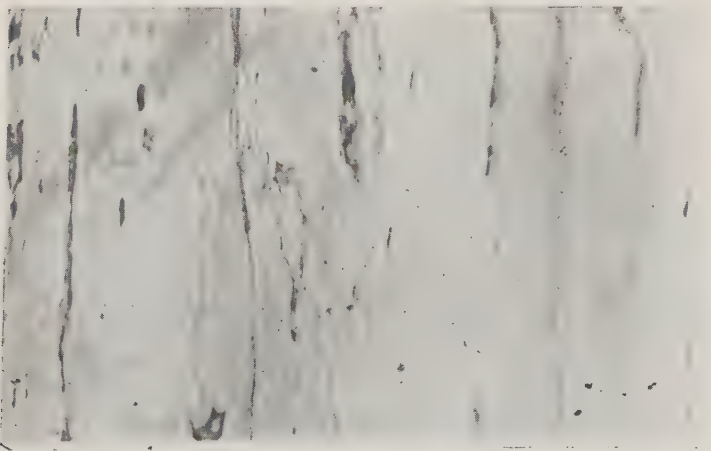
Fig. 189.—Polished slab of sienna marble, Italy. Photo. by C. H. Richardson.

are varying shades of yellow, and often blotched with slightly purplish and violet shades. They are fine grained, compact and receive a polish equal to the Colorado siennas. (6) The Brocatelle marble is of a uniform yellow color and quarried at Monte Arenti, in Montagnola. It is considered by many the
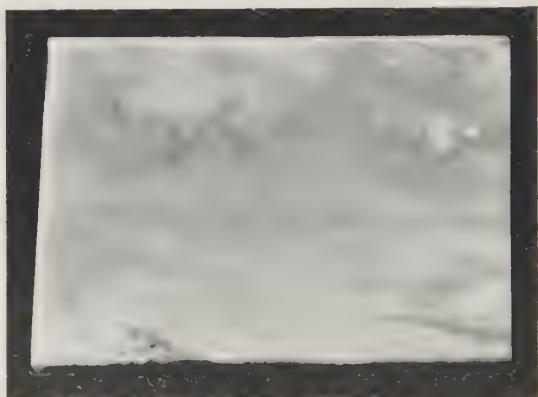
Fig. 190.—Polished slab of brocatelle marble, Italy. Photo. by C. H. Richardson.
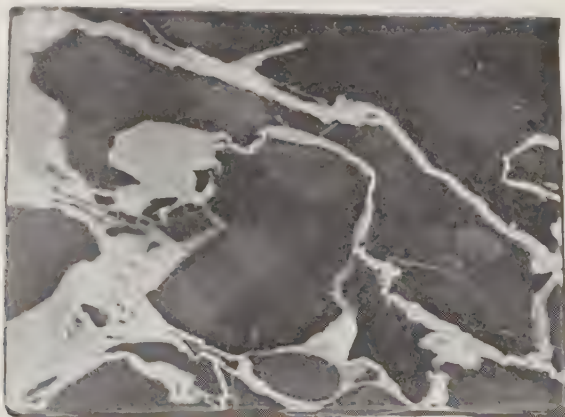
Fig. 191.—Polished slab of black and gold marble, Italy. Photo. by C. H. Richardson.

most beautiful of all siennas. (7) Portor or black and gold marble is found on the Isle of Palmaria. It is a black siliceous limestone traversed by yellowish, reddish and brown veins of the carbonate of iron. The stone receives a high polish and is
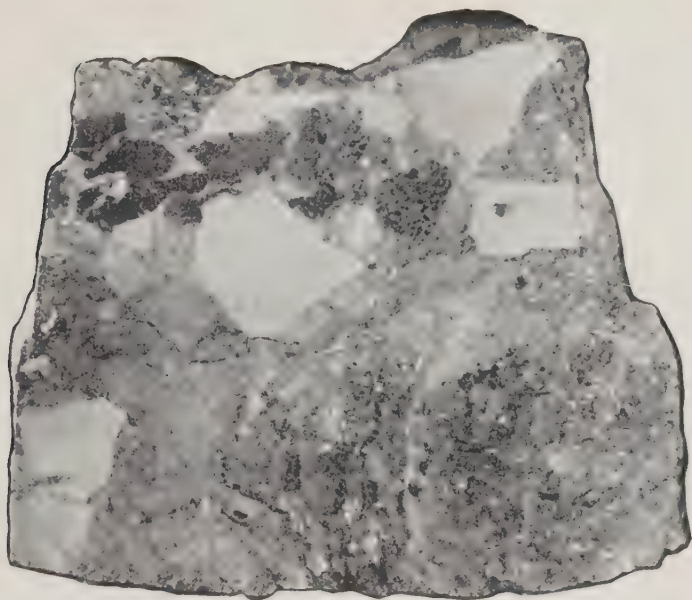
Fig. 192.—Polished slab of breccia marble, Italy.   Photo. by C. H. Richardson.

Fig. 193.—Polished slab of skyros marble, Greece.   Photo. by C. H. Richardson.

prized for decorative interior work. (8) Black marble. This
stone is brought from the Colonnata quarries and closely re-
sembles the Irish black marble. (9) Breccia marble. This
consists of small bluish white fragments cemented together
by a chalk-red cement. A second variety has both white and
red fragments similarly cemented. (10) Ruin marble. This
is a very compact yellowish or drab limestone, the beds of
which have been fractured in every conceivable direction and
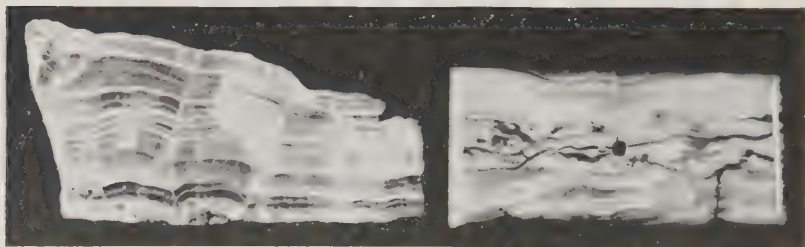
Fig. 194.—Polished slabs of onyx marble, Mexico. Photo. by C. H.
Richardson.
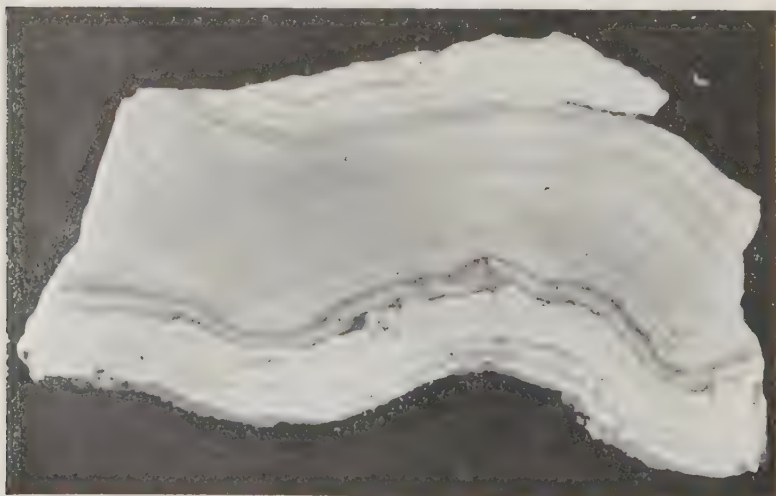
Fig. 195.—Polished block of stalagmite marble, Nova Scotia. Photo.
by C. H. Richardson.

cemented together again. The rock is strictly speaking a
breccia. When cut and polished the slabs have somewhat the
appearance of mosaics, representing the ruins of ancient
castles or other structures. Hence the name "ruin marble."
(See Figs. 189, 190, 191 and 192.)
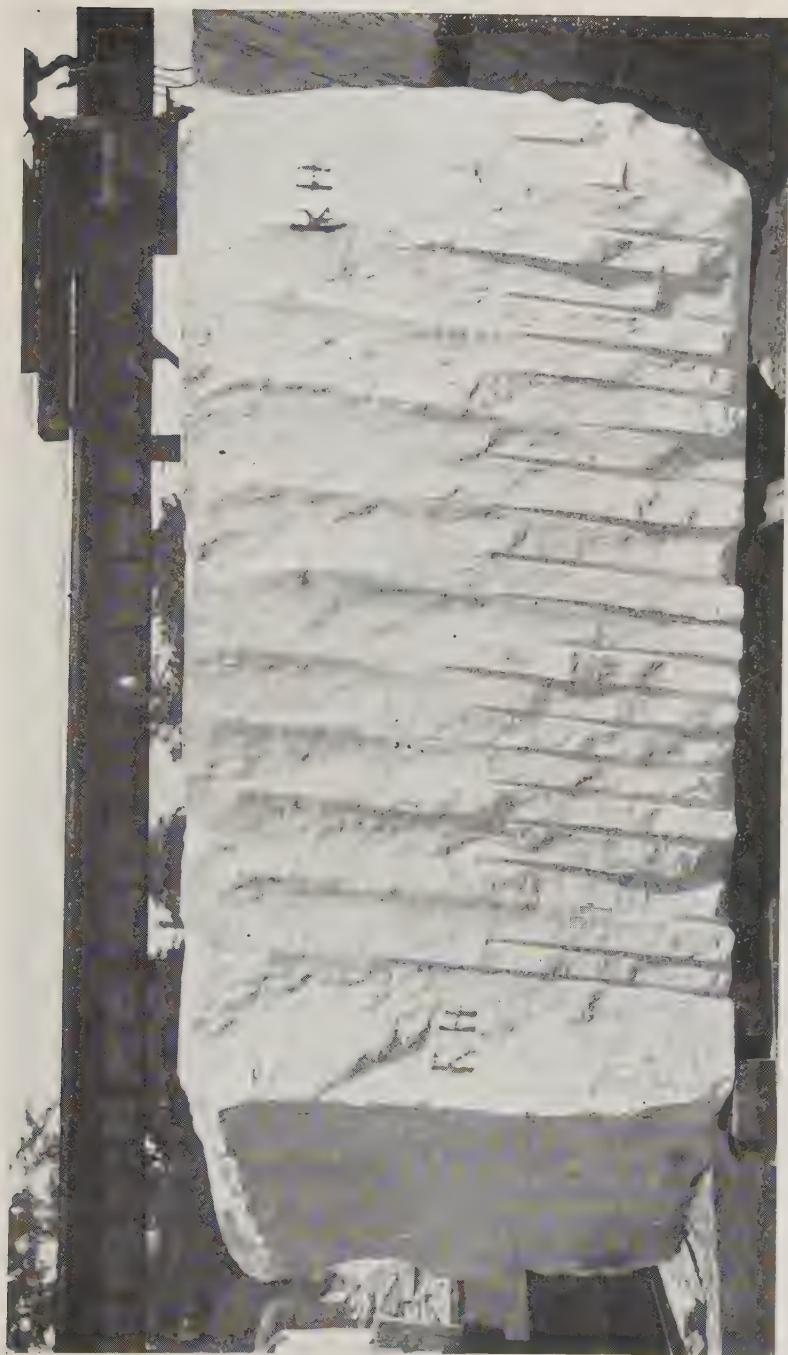
Fig. 196.—Block of marble quarried by the Vermont Marble Company. By courtesy of the Vermont Marble Company.

Fig. 126.—Gadding machine at work in marble quarry at West Rutland, Vermont. By courtesy of the Vermont Marble Company.

Fig. 198.—View of the sheds of the Vermont Marble Company at Proctor, Vermont. By courtesy of the Vermont Marble Company.

Fig. 199.—Rough blocks of marble in the yard of the Vermont Marble Company at Proctor, Vermont. By courtesy of the Vermont Marble Company.

Fig. 200.—View showing the method of handling large columns at Proctor, Vermont. By courtesy of the Vermont Marble Company.

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Greece.—According to R. Swan the Island of Paros in the Grecian Archipelago produces two varieties of high grade marble. The one is a pure white statuary marble of fine grain and even texture. The other is a decorative marble with white body traversed by a network of black veins. The beds vary from 5 to 15 feet in thickness and dip at high angles. The stone near the axis of elevation is of inferior grade. (See Fig. 193.)
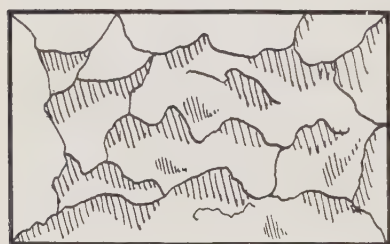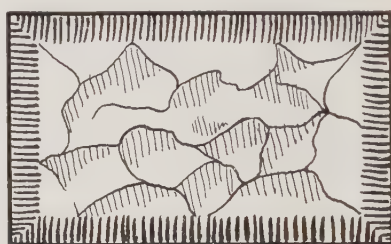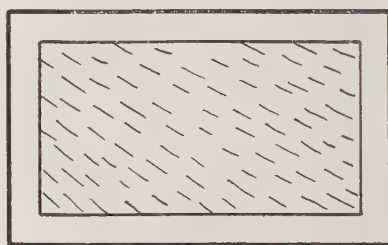
Fig. 201.—Drawings showing difference of dressed stone. A. Rock faced. B. Rock faced with tooled margin. C. Broached stone with tooled margin. D. Rough pointed with tooled margin. Drawings by C. H. Richardson.

Mexico.—The origin and characteristics of the onyx marbles have already been described on pages 137, 154 and 155. (See Fig. 194.)

Nova Scotia.—The stalagmite marbles of Nova Scotia receive a good polish and are well adapted for decorative interior work. (See Fig. 195.)

Ontario.—Bancroft marble represents a remarkably handsome stone that has suffered brecciation and subsequent cementation. Some portions of the quarries do not show

brecciation, while in others the fragments are angular. Polished samples shade from white to pink with a fine mottled appearance in the brecciated portions. It is of even texture and works well.

Hungerford marble is white, bluish, greenish and sometimes pink. It takes a good polish.

Madoc marble shades in color from white, through gray to black.

Renfrew marble is white and used for structural purposes.
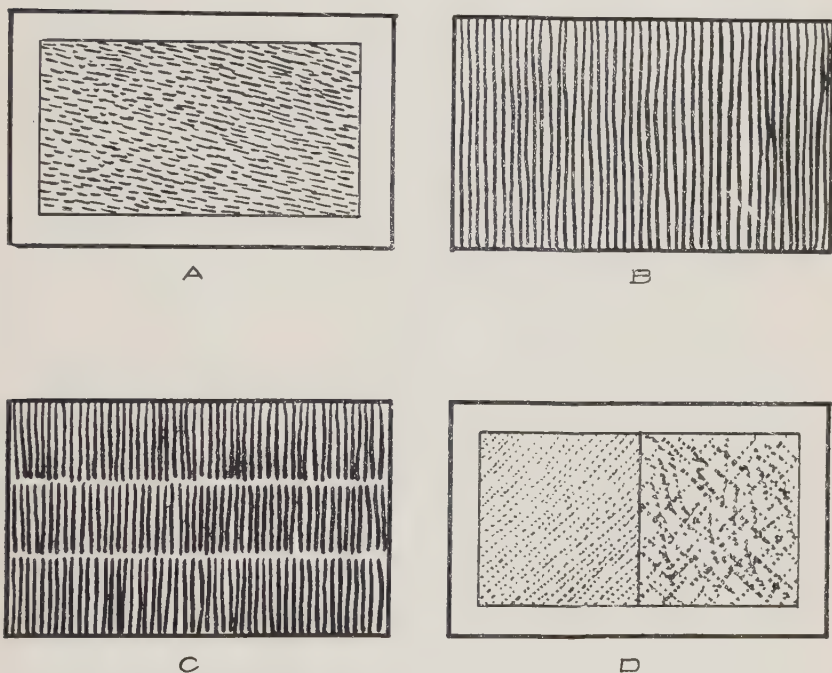
Fig. 202.—Drawings, showing types of dressed stone. A. Fine pointed stone with margin. B. Tooled stone. C. Drove work. D. Crandalled stone with margin. Drawings by C. H. Richardson.

Quebec.—The Province of Quebec produces many marbles that shade in color from white to red and possess a fine grained, even texture. They are used for monumental, structural and decorative purposes.

INDUSTRIAL FACTS ABOUT LIMESTONES AND MARBLES

Quarrying.—In quarrying marble the object is to obtain large blocks of stone with the least disturbance possible. Where

the sheets are too thick to split with wedges the channelling ma-
chine is used to cut vertical channels 2 inches wide and from 4
to 6 feet deep, depending upon the thickness of the block
desired. This machine moves back and forth over the bed or
floor of the quarry. The gadding machine drills holes in the
face of the block to one half the breadth of the block desired.
The stone may then be lifted with wedges. The blocks are
subsequently split into smaller dimensions with wedges, or
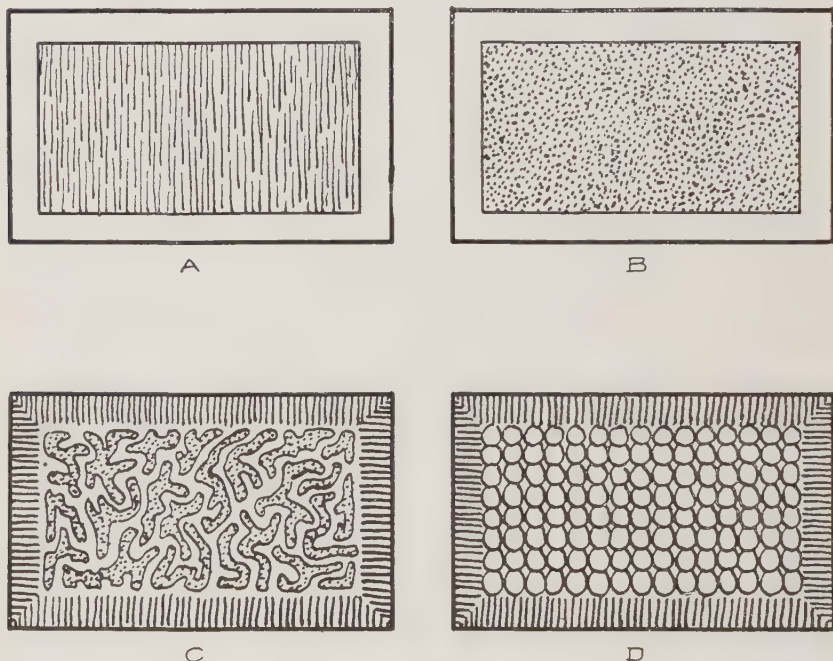
Fig. 203.—Drawings, showing different faces of dressed stone.
A. Patent hammered with margin. B. Bush hammered with margin.
C. Vermiculated work with chiseled margin. D. Fish scale work with
chiseled margin. Drawings by C. H. Richardson.

cut into slabs of varying thickness with a gang of saws.
Emery and chilled iron are used to aid in the cutting. If
possible, explosives should be avoided, as the sudden jar
develops incipient fracture planes that aid in the disintegra-
tion of the stone. (See Figs. 196 and 197.)

Manufacture.—(See Figs. 198, 199 and 200.)

Dressing.—There are many different kinds of finish used for
building stones before they are placed in their position in the

Fig. 204.—Polished pilasters in the interior of the New York Central railway station, Utica, New York, showing royal antique marble from Pittsford, Vermont. By courtesy of the Vermont Marble Company.

Fig. 205.—View in the waiting room of the New York Central Station, Utica, New York, showing royal antique marble from Pittsford Vermont. By courtesy of the Vermont Marble Company.

Fig. 206.—One side of the interior of the New York Central Station at Utica, New York, showing the decorative effect of royal antique marble. By courtesy of the Vermont Marble Company.
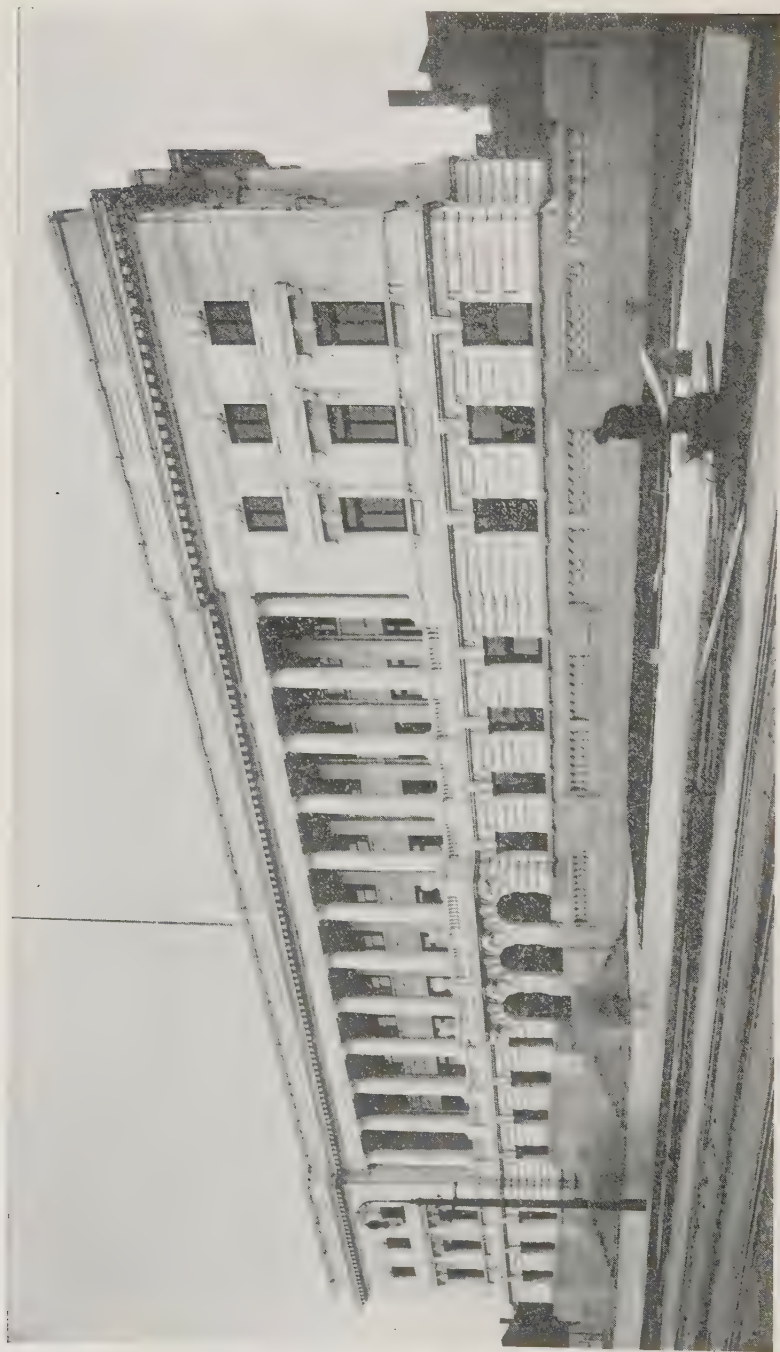
Fig. 207.—City Hall, Trenton, New Jersey, built of tool finished marble from West Rutland, Vermont. Spencer Roberts, architect. By courtesy of the Vermont Marble Company.

wall of the structure. (1) In cobble houses either glacial erratics (in the northern portions of the United States), or angular fragments of rock from quarry products, are laid in the usual bond. These produce unique structures that are pleasing in their effect.

(2) *Rock Face.*—Ashlar blocks are laid practically as they come from the quarry, having been trimmed to a uniform size.

Fig. 208.—Post Office, Montpelier, Vermont, built of Proctor, Vermont, marble. Photo. by C. H. Richardson.

Sometimes the stone is decorated with a margin of drove work. (See Fig. 201.)

(3) *Uniform Pointed.*—These blocks are trimmed to correct dimensions and the outer face is then dressed with a pointing instrument. The stone is decorated with a margin of drove work. (See Fig. 202.)

(4) *Diagonal Pointed.*—This stone differs only in facial appearance from the former, in that the pointing runs in diagonal lines at an angle of 45° across the stone.

(5) *Square Drove.*—The appearance of the face here is produced by a wide chisel with smooth edge. The lines through the center of the stone run parallel with the base of the block. The margin is decorated with drove work.

(6) *Toothed Chisel.*—The toothed chisel produces in the center of the face a surface that somewhat resembles tapestry. The margin is decorated as in the previous cases.

Fig. 209.—Capitol cut from Vermont white marble. Photo. by C. H. Richardson.

(7) *Hammered Face.*—Pean hammers, patent hammers and bush hammers produce different kinds of faces that are fairly smooth and somewhat resemble the pointed face finish. They are usually decorated with a margin of drove work. (See Fig. 203.)

(8) *Grooved Face.*—The face of the stone here produces a grooved effect. The shallow grooves run across the entire face parallel with the bed.

(9) *Sawed Face.*—In this case the blocks of stone are set as they are sawed out at the mill. Fine regular lines traverse the face.

(10) *Smooth Face.*—The sawed stone is faced with a perfectly smooth unpolished surface. It may or may not have a margin of drove work.

(11) *Polished Face.*—The sawed or chiseled face is rendered perfectly uniform and smooth by setting the entire block in a bed of plaster of Paris and using in the order given, chilled iron, coarse emery, fine emery, diatomaceous earth and putty powder or oxalic acid. When oxalic acid is used in the process

Fig. 210.—Entrance to Green Mountain Cemetery, Montpelier, Vermont, built of marble from West Rutland, Vermont. Photo. by C. H. Richardson.

of polishing the expense and time element are less but the polish is short lived. Many decorative marbles and granites in our cemeteries that now appear dull owe this condition largely to the use of oxalic acid in the process of buffing. Putty powder which consists largely of the oxide of tin produces a more expensive, more lasting and far more satisfactory polish.

Hammered Finish.—The cost of finishing stone is determined partly by the shape and largely by the smoothness of the surface desired. The stone is finished by beating it with hammers con-

Fig. 114.—Stephen A. Douglas Memorial, Brandon, Vermont.
Photo. by J. F. Glasson.

taining blades set at various widths. The number of blades to the inch determines the fineness of the surface that can be secured.

For step work, approaches and the upper stories of high buildings, four cuts to the inch give a satisfactory finish. Four-cut work is specified by the United States Government for postoffice base courses. Many commercial buildings are made in this finish.

Six-cut work is the standard for bank fronts, private residences, state capitols, city halls, railroad terminals, art museums, fine bridges, and in general the better class of public and private buildings.

Eight-cut work is often specified on large public memorials, elaborate bank and building entrances, garden work, fountains, mausoleum roof stones and elevated statuary groups.

Ten-cut finish is generally used on monuments, mausoleums, statuary, and other work which demands a special smoothness of surface. Good stone with ten-cut bushing shows a surface smooth as velvet and free from imperfections.

Uses.—The limestones are used in the manufacture of white lime or tinted limes. A larger percentage of limestone proper goes into this field than all other uses combined. This lime product finds use not only in structural work but in the beet sugar industry. Limestones are used for building purposes when they are of fairly uniform color and texture. They are used sometimes for paving blocks but are not resistant to abrasion, and for curbings and gutters. They find large use as a flux in the treatment of iron ores and in the manufacture of the numerous grades of Portland cement. They are used also as a fertilizer and in the manufacture of glass.

The marbles find their largest uses in structural and monumental work. The decorative marbles are used for pillars, colonnades, wainscoting, panels, baseboards, flooring, tiling, firejambs, lintels, counters, shelves, clocks and table tops. The beautiful onyx marbles find use not only for decorative interior work but also in soda fountains, shelves, table tops and clocks. (See Figs. 204, 205, 206, 207, 208, 209, 210 and 211.)

Compression Tests.—The average strength of marbles is not as great as that of granite. Good structural work should resist from 12,000 to 18,000 pounds to the square inch. Some friable marbles fall under these figures and many good marbles exceed them. In nearly all cases they are far above the strength required, even with the builders' margin of safety added to the superincumbent weight.

The following shows the compressive strength of some of the important limestones, marbles and dolomites:

	Lbs. Per Sq. In.
1. Caen, France	3,550
2. Bedford, Indiana	10,125
3. Italian marble, Rutland, Vt.	11,892
4. Italian marble, Italy	12,156
5. Tuckahoe, N. Y.	13,076
6. Tate, Georgia	13,680
7. Rutland, Vermont	13,864
8. Washington, Vermont	17,675
9. Tennessee marble	18,100
10. Cockeysville, Maryland	20,400
11. Lee, Massachusetts	22,860
12. Colville, Washington	24,000
13. Champlain marble, Vermont	25,000

Analyses.—A few analyses are here given as a matter of reference.

1. Oolitic limestone, Bedford, Indiana.

Calcium carbonate, $CaCO_3$	97.26%
Magnesium carbonate, $MgCO_3$	0.37
Ferric oxide and alumina, Fe_2O_3 and Al_2O_3	0.49
Silica, SiO_2	1.69
	99.81

2. Sample from Siluria, Alabama.

Calcium carbonate, $CaCO_3$	98.91
Magnesium carbonate, $MgCO_3$	0.58
Ferric oxide and alumina, Fe_2O_3 and Al_2O_3	0.63
Silica, SiO_2	0.10
	100.22

3. Marble from Plymouth, Vermont. Analysis made by T. S. Hunt.

Calcium carbonate, $CaCO_3$	53.9
Magnesium carbonate, $MgCO_3$	44.7
Ferric oxide and alumina, Fe_2O_3 and Al_2O_3	1.3
	99.9

4. Marble from Brandon, Vermont. Analysis made by D. Olmstead.

Calcium carbonate, $CaCO_3$	99.55
Silica, SiO_2	0.29
Water, H_2O, and loss	0.20
	100.04

5. Marble from Isle La Motte, Vermont. Analysis by D. Olmstead.

Calcium carbonate, $CaCO_3$	87.94
Magnesium carbonate, $MgCO_3$	4.56
Ferric oxide and alumina, Fe_2O_3 and Al_2O_3	2.60
Silica, SiO_2, and other insoluble matter	4.80
Water, H_2O, and loss	0.10
Oxide of manganese	Trace
	100.00

6. Siliceous limestone, Danville, Vt. Analysis by D. Olmstead.

Calcium carbonate, $CaCO_3$	53.50
Magnesium carbonate, $MgCO_3$	2.20
Ferric oxide and alumina, Fe_2O_3 and Al_2O_3	1.90
Silica, SiO_2, and insoluble silicates	38.90
Water, H_2O, and loss	3.50
	100.00

7. Sample from Carrara, Italy.

Calcium carbonate, $CaCO_3$	99.77
Magnesium carbonate, $MgCO_3$	0.90
Silica, SiO_2	0.16
Ferric oxide and alumina, Al_2O_3, Fe_2O_3	0.08
	99.91

8. Sample of white Norwegian marble from Velfjorden, Troviken.

Calcium carbonate, $CaCO_3$	99.27
Iron carbonate, $FeCO_3$	0.137
Manganese carbonate, $MnCO_3$	0.0026
Magnesium carbonate, $MgCO_3$	0.68
Insoluble matter	0.77
	100.86

9. Sample of marble from Lee, Mass.

Calcium carbonate, $CaCO_3$ 54.16
Magnesium carbonate, $MgCO_3$ 45.09
Iron carbonate, $FeCO_3$ 0.32
Insoluble matter 0.46

                                            ———— ——
                                            100.03

10. The following composite analysis of 498 constructional limestones was furnished by H. N. Stokes.

Silica, SiO_2 .... 14.09
Titanium dioxide, TiO_2 .... 0.08
Alumina, Al_2O_3 .... 1.75
Iron oxides, Fe_2O_3, FeO 0.77
Manganous oxide, MnO 0.03
Calcium oxide, CaO 40.60
Magnesia, MgO 4.49
Potash, K_2O 0.58
Soda, Na_2O 0.62
Lithia, Li_2O .... Trace
Water combined, H_2O 0.30
Water uncombined and organic matter........ 0.88
Phosphorous oxide, P_2O_5 .... 0.42
Carbon dioxide, CO_2 .... 35.58
Sulphur, S 0.07
Sulphur trioxide, SO_3 .... 0.07
Chlorine, Cl 0.01

                                            ———— ——
                                            100.34

TABLE SHOWING THE SPECIFIC GRAVITY; STRENGTH PER SQUARE INCH; WEIGHT PER CUBIC FOOT AND RATIO OF ABSORPTION OF SOME LIMESTONES AND MARBLES

Kind and Locality	Size of Cube, Inches.	Position	Strength per Sq. In.	Specific Gravity	Lb. Weight per Cu. Ft.	Ratio of Absorption	Remarks
Dolomite, Joliet, Ill.	2	Bed	14,775	2.56	160	1/94	Average of three trials burst without cracking.
Limestone, Greensburgh, Ind.	....	....	16,875	....	169.98	1/117	
Limestone, Mt. Vernon, Ind.	....	....	15,750	....	165.43	1/156	
Limestone (Oolitic), Bedford, Ind.	....	....	6,500	....	147.03	1/24	
Limestone (Oolitic), Bedford, Ind.	....	....	10,125	....	152.39	1/32	
Dolomite (Marble), Lee, Mass.	5.91x 5.92x 5.92	End	22,860	....	....	....	Sustained maximum load of test machine without apparent injury.
Limestone, Lime Isle, Mich.	2	Bed	19,476	2.54	159	1/90	Average of three trials burst without cracking.
Dolomitic limestone, Red Wing, Minn.	2	Bed / Edge	23,000 / 23,250	2.595	162.2	1/40	
Dolomitic limestone, Kasota, Minn.	2	Bed / Edge	18,500 / 16,750	2.519	157.4	1/28	
Magnesian limestone, Glens Falls, N. Y.	2	Bed	11,475	2.700	168.8	....	Burst without cracking.
Magnesian limestone, Glens Falls, N. Y.	2	Edge	10,750	2.700	168.8	....	Burst without cracking.
Magnesian limestone, Lake Champlain, N.Y.	2	Bed	25,000	2.75	171.9	....	Burst without cracking.
Magnesian limestone, Lake Champlain, N.Y.	2	Edge	21,500	2.75	171.9	....	Burst without cracking.
Magnesian limestone, Canajoharie, N. Y.	2	Bed	20,700	2.685	169.8	....	Burst without cracking.
Magnesian limestone, Canajoharie, N. Y.	2	Edge	13,250	2.685	169.8	....	Burst without cracking.
Limestone, Kingston, N. Y.	2	Bed	13,900	2.69	168.2	....	Burst without cracking.
Limestone, Kingston, N. Y.	2	Edge	11,050	2.69	168.2	....	Average of four trials burst without cracking.
Dolomite (Marble), Tuckahoe, N. Y.	2	Bed	13,076	2.837	177.6	....	
Limestone (Marble), Montgomery Co., Pa.	6.55x 6.05x 6.02 5.94x 5.90x	Bed	13,700	....	....	....	Block split along stratification.
Limestone, Conshohocken, Pa.	5.92	End	14,090	....	....	....	
Limestone (Marble), Dorset, Vt.	2	Edge	8,670	2.683	167.8	1/170	Crushed with slight explosion.
Limestone (Marble), Dorset, Vt.	2	Bed	7,612	2.635	164.7	1/19	Crushed with slight explosion.
Limestone (Tertiary), Caen, France	2	Bed	3,550	1.900	118.8	....	Average of two trials burst without cracking.
Limestone (Marble), Italy	2	Bed	12,156	2.690	168.2	....	Burst without cracking.
Quartzose marble, Washington, Vt.	2	Bed	17,675	....	....	....	

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REFERENCES

Aubury, L. E.—Structural and Industrial Materials of California; 1906.

Baker, R. T.—Building and Ornamental Stones of New South Wales, 2nd. Edition; Technological Museum, 1909.

Beare, T. H.—Building Stones of Great Britain; London, 1892.

Brinsmade, R. B.—Marble Quarrying of Gouverneur, N. Y.; Eng. and Min. Journal, Vol. 80, 1905.

Buckley, E. R.—Building and Ornamental Stones of Wisconsin; 1898.

Burnham, S. M.—History and Uses of Limestones and Marbles; Boston, 1883.

Butts, L.—Variegated Marble Southeast of Calera, Shelby County, Ala.; Bull. U. S. Geol. Survey, No. 470, 1911.

Byrne, P.—Marble Formations of the Cahaba River, Alabama; Eng. and Min. Journal, Vol. 72, 1901, p. 400.

Clute, F. P.—History of the Marble Industry in Tennessee; Fifth Ann. Report, Bureau of Labor, Statistics and Mines, Nashville, 1896.

Dale, T. N.—The Commercial Marbles of Western Vermont; Bull. U. S. Geol. Survey, 521, 1912.

Dale, T. N.—The Calcite Marble and Dolomite of Eastern Vermont; Bull. U. S. Geol. Survey, 589, 1915.

Day, A. W.—The Marble Quarries of Carrara, Italy; Sci. Am., Nov. 26, 1907.

Eckel, E. C.—Building Stones and Clays; Their Origin, Characters and Examination; John Wiley and Sons, 1912.

Gordon, C. H.—The Marbles of Tennessee; Tennessee Geol. Survey, 1911.

Herrmann, O.—Steinbruch - Industrie und Steinbruch - Geologie; Berlin, 1899.

Hopkins, T. C.—Marbles and Other Limestones; Ann. Report Geol. Survey of Arkansas, Vol. 4, 1893.

Howe, J. A.—The Geology of Building Stones; E. Arnold, London, 1910.

Hull, Edward—A Treatise on the Building and Ornamental Stones of Great Britain and Foreign Countries; E. Arnold, London, 1910.

Humphrey, H. L. — Fire-Resistive Properties of Various Building Materials; Bull. U. S. Geol. Survey, No. 370, 1909.

Jackson, A. W.—Building Stones of California; Ann. Report, State Mineralogist, 1888.

Julien, A. A.—The Durability of Building Stones; Tenth Census U. S., Vol. 10, 1884, pp. 366-367.

Julien, A. A.—The Decay of the Building Stones of New York City; Trans. New York Acad. Sci., Vol. 2, 1882-1883, pp. 67-79, 120-138.

Keith, A.—Tennessee Marbles; Bull. U. S. Geol. Survey, No. 213, 1902.

Lee, A.—Marble and Marble Workers; 1887.

McCalley, Henry—The Coosa Valley Region; Report on the Valley Regions of Alabama, Pt. 2, Alabama Geol. Survey, 1897.

McCallie, S. W.—A Preliminary Report on the Marble of Georgia; Bull. Geol. Survey of Georgia, No. 1, 1894.

Mathews, E. B.—An Account of the Character and Distribution of Maryland Building Stones, Vol. II, Maryland Geol. Survey, 1898.

Mathews, E. B. and Grasty, J. S.—Report on the Limestones of Maryland; Vol. VIII, Part III, Maryland Geol. Survey, 1909.

Merrill, G. P.—Stones for Building and Decoration; 3rd Ed., 1908.

Middleton, G. A.—Building Materials; London, 1905.

Parks, W. A.—The Building Stones of Canada; Can. Mines Branch, Vol. I: Rept. No. 100 (Ontario); 1912. Vol. II: Rept. No. 203 (Maratime Provinces); 1914. Vol. III: Rept. No. 279 (Quebec); 1914. Vol. IV: Rept. No. 388 (Western Provinces); 1916.

Perkins, G. H.—Report on the Marble, Slate and Granite Industries of Vermont; 1898.

Perkins, G. H.—Report of the Vermont State Geologist; 1914.

Prouty, W. F.—Crystalline Marbles of Alabama, Bull. G. S. A., Vol. 27, No. 2.

Prouty, W. F.—Marbles of Alabama; Bull. Geol. Survey of Ala., No. 18, 1916.

Richardson, C. H.—The Terranes of Orange County, Vermont; Ann. Report State Geologist, 1902.

Ries, H.—Economic Geology; John Wiley and Sons, New York, 1916.

Ries, H.—Building Stones and Clay Products; J. Wiley and Sons, 1912.

Schmid, H.—Die Modernen Marmore und Alabaster; Leipsig and Vienna, 1897.

Shedd, S.—The Building and Ornamental Stones of Washington; Ann. Report Washington Geol. Survey, Vol. 2, 1903.

Watson, J.—Building Stones; Cambridge Press, 1911.

Wright, C. W.—The Building Stones and Materials of Southeastern Alaska; Bull. U. S. Geol. Survey, No. 345, 1908.

CHAPTER V

SANDSTONES

Definition.—Sandstones belong to the sedimentary and detrital rocks. They represent the reconsolidated products of rock decomposition. They consist, therefore, of grains of sand held together by some cementing material. Pressure alone may accomplish this as in the flexible sandstone of North Carolina, or it may be effected by the addition of some cementing material.

Chemical Composition.—Sandstones differ in composition as widely as the sands of the sea shore or the river banks. In one respect there is a wide difference and that is the presence of the cementing materials. Essentially they represent grains of quartz, SiO_2, and some cement. There are many other minerals like the amphiboles, pyroxenes, magnetite, chromite, cassiterite and monazite that may resist decomposition and remain near the place where they were derived as sand.

Impurities.—The impurities are the minerals normal to the sand beds that suffered cementation and their metamorphic derivatives. Siderite, pyrite, garnet, muscovite and biotite may appear. These can all be detected by methods already cited.

Texture.—The texture of sandstones varies from the fineness of dust particles, sandy material that may be held in suspension for a considerable period of time and deposited, to individual pieces several inches in diameter. When these larger rock fragments are water worn and well rounded the stone passes over into a conglomerate. When the fragments are distinctly angular the stone becomes a breccia. The term conglomerate is sometimes used to cover the breccias. In the case of the conglomerates the fracture is often around the coarser fragments and in the quartzites across them. (See Fig. 212, and also Fig. 10.)

Color.—The color of sandstones is widely varied. It may arise from the color of the individual sand grains themselves or from the character of the cements introduced. The color is more dependent upon the nature or composition of the cementing material than it is upon the color of the sand grains.

Fig. 212.—Fine grained red sandstone, Portage, Wisconsin. Photo. by C. H. Richardson.

Fig. 213.—Brownstone, Hummelstown, Pennsylvania. Photo. by C. H. Richardson.

If the cement is the anhydrous oxide of iron the stone will be red. If it is the hydrated oxide of iron the stone will be yellow or yellowish brown. If it is clayey matter the stone may be gray or blue. Blue coloration may also be caused by microlites of pyrite, and the gray by microlites of siderite. If the cement is pure silica and the original sand grains consisted of white quartz the metamorphic product, quartzite, will be white. The prevailing colors are white, light gray, gray, drab, blue, buff, yellow, yellowish brown, reddish brown and red. (See Figs. 213, 214 and 215.)

Varieties.—The different varieties are based upon several factors as mineral composition, structure, and the character of the cementing material. The cementing material may be calcium

Fig. 214.—Reddish brown sandstone, Potsdam, New York. Photo. by C. H. Richardson.

carbonate. The product is then called a calcareous sandstone. It passes by insensible gradations into a siliceous limestone. A kaolinitic sandstone is one whose cement is kaolinite. A glauconitic sandstone is one containing green sand marl. An argillaceous sandstone is one bearing a considerable amount of clayey matter. It may pass insensibly into a shale. A ferruginous sandstone is one bearing some compound of iron. Such sandstones may reveal the presence of the iron by their color. A bituminous sandstone is one bearing bitumen. It emits an organic odor when strongly heated. A feldspathic sandstone, as the name implies, contains fragments of feldspars in addition to the grains of silica or quartz. Its parent source was the decomposition of some granite or gneiss. In its metamorphism it passes into a gneiss.

A quartzite is a metamorphic sandstone whose cement is silica. A greywacke is a sandstone consisting essentially of quartz, feldspar and fragments of slate, bound together by argillaceous, calcareous, or even feldspathic material. According to C. P. Berkey secondary chlorite constitutes the main bonding material in the Hudson River bluestone. Flagstone is a name derived from the ease with which a sandstone splits into slabs suitable for flagging or sidewalks. Freestone is the name applied to the varieties of sandstone that split freely in all directions. (See Fig. 216.)

Fig. 215.—Blocks of gray sandstone, Cobleskill, New York, designed for constructional work in New York City. Photo. by C. H. Richardson.

Cements.—The cements in sandstones are as varied as the sandstones themselves. Pressure alone may cause the sand grains to interlock and produce a friable and flexible variety known as itacolumyte. Percolating waters charged with calcium carbonate provide the carbonate for binding the sand grains together. This cement may be identified by its effervescence with cold dilute HCl. The amount of this cementing material may be quite subordinate, or the percentage of cement may equal that of the sand.

A. von Morlot cites calcite crystals from Fontainebleu that contain 50 per cent of calcium carbonate, others that carry

58 per cent of sand and still others that bear 95 per cent. of sand. S. L. Penfield and W. E. Ford have shown the composition of similar calcites from the Bad Lands of South Dakota to be 60 per cent of sand and 40 per cent of calcium carbonate.

L. Cayeux describes the gaize of the French geologists as

Fig. 216.—Jeudevine memorial library, Hardwick, Vermont, built of Triassic sandstone from the Connecticut Valley. Photo. by C. H. Richardson.

a siliceous sandstone containing quartz and glauconite which are cemented together by opaline silica, clay, chalcedony and the carbonate of lime. The percentage of calcium carbonate is usually small, but in some instances it has risen sufficiently high to cause the rock to be called a calcareous sandstone. The silica ranges from 76 per cent to 92 per cent and is soluble

in caustic alkalies up to 75.3 per cent. Ordinary quartz is sparingly soluble in a weak alkali, but opaline silica passes readily into solution.

Silica itself may serve as the cementing substance. It may appear either as the amorphous silica or in crystalline form. In the former case the silica fills the interstices between the sand grains, while in the latter case the sand grains themselves become the nuclei for distinct quartz crystals. C. R. Van Hise in his classic "Treatise on Metamorphism" states that when the sand grains are of equal dimensions the maximum pore space reaches 24 per cent, but the actual space on account of the irregularity or inequality of the grains is usually much greater. With silica as a cement there is every gradation possible between a friable rock and a compact solid rock which in its metamorphism passes into a hard, vitreous quartzite with the longest life of any known building stone.

The anhydrous and hydrous oxides of iron serve often as the cementing material. These cements impart their charactertistic colors to the sandstone in which they appear. Hematite tends to impart a red color. The sandstones of the southern shore of Lake Superior bear this cement. The Triassic sandstones of New England bear limonite and turgite. The Tertiary sandstones of the Appalachians carry turgite. Some of these sandstones are fairly permanent.

The hydroxide of aluminum as well as clayey matter may fill the interstitial spaces between the sand grains and form a fairly satisfactory stone for structural work. The fine grained bluestone of Warsaw, N. Y., carries clay. It is detected by its argillaceous odor and aluminous taste. According to G. P. Merrill clayey matter is objectionable as a cement because it readily absorbs water and renders the stone more subject to injury by frost.

F. Clowes cites barytic sandstones in which barium sulphate serves as the cement. Sometimes more than 50 per cent of $BaSO_4$ is present. The waters in this case percolating through the sand beds bore barium carbonate and soluble sulphates which would react upon each other, forming barium sulphate and some soluble carbonate. Such a sandstone would be most durable on account of the insolubility of the cementing material.

B. Doss has described crystals of gypsum from the Astrakan steppe which contain 48.58 per cent of sand and also cites gypsiferous sandstones. C. W. Hayes has described a sandstone from Tennessee in which calcium phosphate serves as

the matrix of the sand grains. C. Claus cites a sandstone from Kursk, Russia, that bears 22.64 per cent of calcium phosphate. G. P. Merrill cites the phosphates of iron as rare cementing material in sandstones. M. Mackie cites calcium fluoride as the cement in the sandstones from Elginshire, Scotland, which in exceptional cases bears 25.88 per cent fluorite. F. W. Clarke cites bituminous substances serving as cement and further states that any substance which waters can deposit in a relatively insoluble condition may serve as a cement.

Origin.—Sandstones are sedimentary or detrital in origin. beds of sand deposited by waters when their velocity was checked ultimately became consolidated by the influence of any one, or more than one, of the cements already enumerated. Any rock forming mineral which can survive the destruction of the parent rock mass may appear amongst the sand deposits and therefore be present in the resulting sandstones.

Age.—Sandstones are not confined to the rocks of any particular geological age. They appear in the rocks of all ages from the Archaean to the present time. Commercial sandstones, however, are not younger than the Cretaceous.

AMERICAN SANDSTONES

Alabama.—Sandstones of Lower Carboniferous age have been worked in this state at Cherokee, Colbert County. They are known as the Hartswellville stone. Carboniferous sandstones are quarried at Cullman, Jasper and Tuscaloosa. These sandstones are used largely in river engineering. The Weisner quartzite is used for structural purposes. It is of Cambrian age.

Arizona.—Triassic sandstones occur in Flagstaff, Yavapai County. They are of fine grain and even texture. They shade in color from a light pink through a brown to red. The cement is calcium carbonate and the oxides of iron.

Arkansas.—According to J. C. Branner the northern part of the state contains a cream colored calciferous sandstone which on account of its color, massiveness, and firmness, is desirable for achitectural purposes. D. D. Owen cites brown massive sandstones in Van Buren County. Gray sandstones of Carboniferous age are also quarried. Buff colored sandstones occur in the Boston Mountains. They have been quarried somewhat in the northwestern part of the state. The Batesville sandstone of Independence County is cream colored

and used largely in the construction of the business section of Batesville.

The peculiar novaculites of Arkansas which have been so widely used as hones are worthy of special mention. L. S. Griswold considered them as a siliceous sediment or silt, and, therefore, a sandstone of extremely fine grain. He found no organisms in the novaculite and no appreciable amount of soluble silica. All gradations exist between shale and novaculite. F. Rutley considers the novaculite a replacement deposit or pseudomorph after limestone or dolomite. The novaculite has also been regarded as a chemical precipitate, analogous to siliceous sinter. Whatever its origin may have been it is exceedingly fine grained and nearly pure silica.

California.—The sandstones of Alameda County are used for macadam, rubble, concrete, foundations and cemetery work. The stone is massive and buff colored. Amador County is the home of the red sandstone used in the California Bank Buildings at Sacramento, and in the Chronicle Building at San Francisco. About 300 feet to the north of the red quarry there occurs a massive snow-white sandstone that is free from iron and well adapted for constructional work. The waste can be used by the glass and pottery manufacturers. Calaveras County has produced a medium grained, white sandstone. Colusa County produces a bluish gray and buff sandstone that occurs in beds totalling from 125 to 225 feet in thickness. Contra Costa County furnishes a fine grained, light blue sandstone that makes a firm building stone. Kern County produces sandstones that are fine grained, drab, blue, tan, red and green in color. Los Angeles County furnishes a fine grained tawny colored sandstone that is represented in the Courthouse at San Bernadino and in the Public Library at Santa Ana. Napa County quarries light gray, bluish gray and buff sandstones that are used locally. Santa Barbara County produces a buff colored, coarse grained arkose sandstone that is used for building purposes. Santa Clara County furnished the buff sandstone for the Carnegie Library at Santa Cruz. Ventura County possesses a coarse grained, rich purplish brown sandstone and a fine grained, light reddish brown stone that works easily and is very durable. The stone is known as the Sespe brownstone and is largely used for constructional work in many cities in the state.

Colorado.—According to G. H. Eldridge the sandstones of the state fall into three distinct varieties, (1) The Fountain sandstone which is fine grained and of light color and well

adapted for a wide variety of architectural purposes. Its age is Pennsylvanian. (2) The second is a hard, banded variety that is a favorite for flagging and foundations on account of its high compression strength. (3) The third is a hard white or creamy white quartzite well suited for curbing, paving, flagging, underpinnings, etc. The Triassic salmon red stone from Jefferson County finds a ready market in Chicago. The light colored sandstone found in the Court House at Denver came from Canon City.

Connecticut.—According to J. D. Dana the well known belt of Triassic sandstones traverses Connecticut and Massachusetts in a north and south direction a distance of 110 miles with an average width of 20 miles. The first known quarrying of sandstone in America antedated 1665 and was executed at Portland and Middletown, where the rocks hang shelving over the river. The Portland beds lie in nearly a horizontal
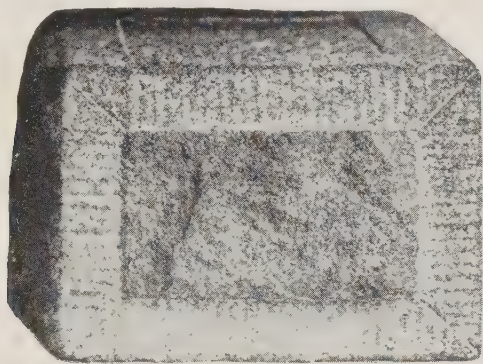
Fig. 217.—Brown sandstone, Middlesex quarry, Portland, Connecticut. Photo. by C. H. Richardson.

position. The vertical walls now rise on three sides for hundreds of feet above the quarry floor. Blocks of any dimension can be obtained. The stone grades from fine to medium in texture and is of uniform reddish brown color. The stone in some localities bears scales of muscovite set with cleavage parallel to the bedding planes of the stone. Such blocks when set on bed are fairly permanent, but if set so that pressure is parallel with the cleavage in the mica the stone shows a tendency to scale upon exposure to the atmosphere. The compression test when made with the stone set on edge is lower than on the bed. (See Fig. 217.)

Georgia.—This state is known to carry in the Chattooga Mountains a wide variety of sandstones of even texture and of white, gray, buff, brown and red colors.

Idaho.—G. P. Merrill cites the presence in the National Museum in Washington of a coarse and light colored sandstone from Boise City.

Illinois.—Sandstones occur in this state in Carroll, Greene, Henry, Marion, Randolph and St. Claire Counties. They shade in color from a light bluish-gray color to a dark brown color. In both color and texture they resemble the Triassic sandstone of the Connecticut valley. They are Carboniferous in age.

Indiana.—According to T. C. Hopkins the Mansfield sandstone is the most important sandstone in the state both from an economic and a scientific standpoint. It is a massive coarse grained stone whose colors are gray, yellow, brown, red and variegated. The quartz grains in the brownstones of Indiana are themselves white or colorless. They are encircled by a film of iron oxides to which the color of the stone is due. The cementing material varies from 2 to 35 per cent. Hopkins further states that there are many shades of the red and brown colors, one of the most common being a deep reddish brown with a faint purple tinge suggestive of manganese, and having a faint steel luster in places. It is a handsome stone and desirable for building purposes. Another common shade is a lighter red than the preceding variety. The lighter color is due in part to the greater abundance of white granular quartz and in part to a thinner coating of the oxide of iron on the grains themselves. It is considered handsomer than the preceding variety. Another shade is a walnut brown. Still another variety is called a "flea-bitten fawn skin." It consists of a light brown body with light gray spots about the size of the tip of the finger. The stone near Green Hill is a little lighter red than a cherry. It is a clearer red than any other sandstone of the state.

The yellow, buff and gray Mansfield sandstone is more abundant than the brown and red varieties. The difference lies largely in the iron content of the cement. The nearly white sandstone is practically free from iron. The Mansfield sandstones are of great durability and preferable to the Triassic brownstones of the Appalachian belt. They are adapted to rock masonry of all kinds where they are not subject to great transverse strain, violent abrasion, or require a smoothly finished or carved surface.

Portland Sandstone.—The Portland sandstone at Worthy, Vermillion County, is one of the best building stones of the state. The stone is of even texture and in color is light buff near the surface and bluish gray with depth. It occurs in massive beds more than 50 feet in thickness and overlain with shale, coal and glacial drift.

Riverside Sandstone.—The Riverside sandstone occurs at Riverside, Fountain County. The stone is extremely fine grained, receives a perfectly smooth finish and is well adapted to delicate carving and ornamentation. In color it is a drab or buff on the exterior, with a light blue interior. It is not as durable a stone as the Mansfield brownstone but it is better adapted to trimming or carved work. (See Fig. 218.)
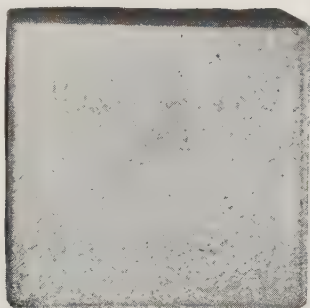
Fig. 218.—Fine grained gray sandstone, Riverside, Indiana. Photo. by C. H. Richardson.

Iowa.—Coarse dark brown sandstones of Carboniferous and Cretaceous ages are quarried in Case and Muscatine Counties.

Kansas.—Sandstones are quarried in the southwestern part of the state in Bourbon, Crawford, Elk, Greene, Labette, Montgomery, Wilson and Woodson Counties. They are fine grained, even textured stones of bluish-gray and brown colors. Their use is largely local.

Kentucky.—In this state sandstones are quarried in Breckenridge, Grayson, Johnson, Simpson and Todd Counties. They are very fine grained and of even texture. In colors they shade from a light buff to a pink and are used locally.

Maine.—Brown and red sandstones of Devonian and Triassic age occur in this state in Washington County and at Machiasport. They are not extensively quarried.

Maryland.—A Triassic sandstone occurs about 30 miles

northwest of Washington in Montgomery County. It is of fine grain and even texture. In color it is a light reddish brown of pleasing effect. It is well adapted for all manner of building and ornamental work. It is one of the most durable of all the Triassic sandstones. It can be seen by any visitor in Washington for the Smithsonian Institution was

Fig. 219.—Crouse College at Syracuse University, Syracuse, New York, built of Triassic sandstone from East Longmeadow, Massachusetts. Photo. by I. U. Doust.

constructed from this stone in 1848-54. G. P. Merrill states that these blocks show few defects from weathering alone and that even these might have been avoided by a more judicious selection of the stone. The walls of the Chesapeake and Ohio Canal contain this stone.

Massachusetts.—The Triassic sandstones of the Connecti-

cut Valley have been quarried from the beginning of the sandstone industry in the United States. The length and breadth of the belt has already been described under the caption of Connecticut. The best known quarries in Massachusetts are located at East Longmeadow and Kibbe, in Hampden County. The stone is of fine grain and even texture. It is of bright brick red color and works easily. It is well adapted to a large variety of combinations in structural work. Crouse College at Syracuse University is from the East Longmeadow quarries. (See Figs. 219 and 220.)

Fig. 220.—National Life Insurance Company's building, Montpelier, Vermont. By courtesy of V. A. Doty.

Roxbury Conglomerate.—This stone often noted as the Roxbury pudding stone occurs in Brookline, Dorchester, Roxbury, and other localities around Boston. In many places the rock is a coarse conglomerate bearing large pebbles of quartz, granite, melaphyre and felsite. In others the texture is sufficiently fine to permit the quarrying and dressing of the stone for structural purposes in and around Boston. The paste in which the pebbles are embedded is greenish gray in color and durable.

Michigan.—The rain-drop sandstone is quarried at Marquette and L'Anse in the Upper Peninsula. It is of medium

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texture and brownish red color often spotted with gray. The gray spots are equally durable with the rest of the stone and produce an effect that is not altogether unpleasing. This sandstone as well as that quarried on the eastern coast of Lake Superior is of Potsdam age. The latter stone is very hard, compact and heavily bedded. (See Fig. 221.)

Lake Superior Sandstone.—This sandstone is quarried at Jacobsville, Keweenaw Bay. The stone is of even texture and bright red color. The Mining School building at Houghton, Michigan, and the basement of the Cornell University Library, Ithaca, N. Y., are from this stone. Quarries are also operated
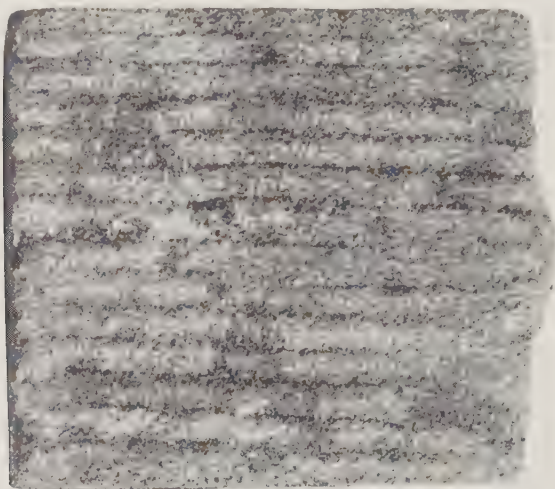
Fig. 221.—Rain-drop sandstone, Marquette, Michigan. Photo. by C. H. Richardson.

in Eaton and Jackson Counties in the Carboniferous formations of the southern part of the state.

Minnesota.—According to N. H. Winchell the Kettle River sandstone is one of the most important building stones of the state. The stone is of fine grain and even texture and of light pink, brown or reddish brown color. (See Fig. 222.)

A very hard, compact and red quartzite occurs in Cottonwood, Pipestone, Rock and Watonwon Counties. The best known quarries are at New Ulm. A deep red sandstone is quarried in Nicollett County and a light colored sandstone in Scott County.

Mississippi.—Sandstones of buff and gray colors and of fine

grain and even texture are known to occur in the state. Their use is only local.

Missouri.—In Carroll and Johnson Counties, near Miami and Warrensburgh, there are quarries of light gray sandstone that weathers well and has been used in several important structures in the state.

Montana.—About fifteen counties in Montana are sandstone producers. According to A. C. Peale the quarries in Gallatin County produce a fine grained, even textured, light gray Cretaceous sandstone. Blocks of large dimensions can be obtained. The stone works easily when first quarried but
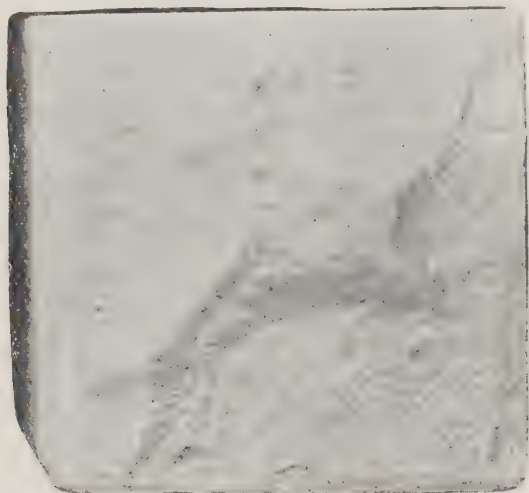
Fig. 222.—Kettle River sandstone, Sandstone, Minnesota. Photo. by C. H. Richardson.

hardens on exposure. Yellowstone County produces a fine textured, bluish gray sandstone of considerable importance. It is found in the Capitol building at Helena, Montana. A compact red quartzite is also quarried near Salesville.

Nebraska.—In this state Dakota County furnishes a very hard compact Cretaceous quartzite well suited for structural purposes, and Memaha County supplies a fine grained flagging stone for local consumption.

Nevada.—Sandstones are not extensively quarried in Nevada. A friable coarse textured stone of gray color is quarried to some extent at Carson and used locally. It is very soft and porous.

New Jersey.—Belts of sandstone traverse this state in a northeasterly direction from the Delaware River to the New York boundary. J. V. Lewis classifies the arenaceous rocks as follows: (1) A belt of fine grained, even textured sandstone, white, gray, brown and red in color. They are generally arkose with a cement of silica, or silica and the oxides of iron. They are compact and show little tendency to scale. (2) A belt of sandstone and conglomerates in the Kittatinny Mountains. (3) A quartzite, shading from white to gray in color in the northwestern part of the state. (4) A bluish gray, purple and red argillaceous sandstone near Byram, Lawrenceville and Princeton. (5) Sandstones suitable for flag-

Fig. 223.—A residence at Princeton, New Jersey, built of Princeton argillite. By courtesy of J. Volney Lewis.

ging purposes in Hunterdon, Sussex and Warren Counties. Many of the sandstones of New Jersey are of Triassic age. (See Fig. 223.)

New Mexico.—According to W. G. Tight the commercial sandstones of this state are situated in the vicinity of Alburquerque and Las Vegas Hot Springs. They are of fine grain and even texture. They shade in color from gray to pink.

New York.—The Potsdam sandstone of the Raquette river valley in St. Lawrence County is of Cambrian age. It is the oldest commercial sandstone in the state. Its texture is fine grained to medium. Its color apart from the type locality is grayish white to gray. In the Potsdam quarries the colors are light pink, light red and reddish brown. According to

J. C. Smock its mineral composition is silica with a cement of silica filling the interstices amongst the sand grains and bearing enough of the oxides of iron to give the stone its characteristic tints. It is one of the strongest and most durable of all known sandstones. Representatives of this stone may be seen not only in a large number of buildings in Potsdam, N. Y.,

Fig. 224.—Block of Potsdam sandstone, Potsdam, New York, showing tooled surface. Photo. by C. H. Richardson.

but also in the Florence Flats, Syracuse, N. Y., All Saints Cathedral, Albany, N. Y., and in the Dominion Parliament buildings, Ottawa, Canada. Smock also cites quarries of the Potsdam sandstone at Clayton in Jefferson County, Fort Ann and Whitehall in Washington County, Hammond in St. Lawrence County, Keeseville in Clinton County, Malone in

Franklin County, and Port Henry in Essex County. One of the most notable of the recent structures containing Potsdam sandstone is the new Armory at Rochester, N. Y. (See Fig. 224.)

Hudson River Group.—The sandstones of the Hudson River Group are of quality inferior to the Potsdam sandstone. The stone at Aqueduct, Schenectady County, is fine grained and gray to blue in color. The fine grained and bluish sandstone of Schenectady may be seen in the Memorial Hall at Union

Fig. 225.—Block of red medina sandstone, Medina, New York, showing character of rift. Photo. by C. H. Richardson.

College, Schenectady. This stone has also been quarried at Camden in Oneida County, Highland in Ulster County, New Baltimore in Greene County, Rhinebeck in Dutchess County, Troy in Rensselaer County.

Medina Sandstone.—This sandstone received its name from Medina, Orleans County, where the formation is especially well developed and where characteristic fossils appear in the gray beds. The stone varies from fine grained to medium in texture and in color from gray to red and variegated. The gray variety is popular for paving stone, curbing, etc., while

the red variety is well adapted for structural purposes. It has
found its way into many western cities and is very durable.
J. C. Smock cites additional quarries in the Medina Group at
Albion, Hindsburgh, Holley, Hulberton and Shelby Basin in
Orleans County, at Brockport in Monroe County, Camden in
Oneida County, Lockport in Niagara County, Granby and
Oswego in Oswego County, Sterling in Cayuga County, Wol-
cott in Wayne County. (See Fig. 225.)

Clinton Group.—Sandstones have been quarried in the Clinton
group of sedimentaries at Higginsville in Oneida County.

Devonian Sandstones.—The term Hudson River Bluestone has

Fig. 226.—A slab of sandstone from the Clarke-Conroy quarry,
Norwich, New York. By courtesy of the Clarke-Conroy Company.

been used commercially to designate the fine grained, even
textured compact sandstones of the middle and upper De-
vonian. In the main they are gray or bluish gray in color and
have found use for paving blocks, curbing and flaggings.

The belt of Devonian sandstones 100 miles in length and of
varied width stretches from Albany County in a southwesterly
direction to the Delaware River. The quarries at Dormans-
ville and Reidsville have furnished much flagging stone for
the city of Albany. Ulster County has been a large producer.
The towns in which the bluestone has been quarried are
Hurley, Kingston and Saugerties. It has been quarried in a

large number of towns in the valley of Rondout creek and its
tributaries.

Another economic group of sandstones mostly in the upper
Devonian, stretching in an east and west direction nearly
across the state has been quarried in Coventry, Guilford,
Norwich, Smithville Flats and South Oxford in Chenango
County; in Cooperstown and Oneonta in Otsego County; in
Ithaca and Trumansburgh in Tompkins County; Penn Yan,
Yates County; Portage in Livingston County; Watkins in
Schuyler County and Warsaw in Wyoming County. The

Fig. 227.—Block of Norwich bluestone, Oxford, New York, show-
ing planed surface. Photo. by C. H. Richardson.

Warsaw bluestone is extremely fine textured and dresses
easily. It is especially well adapted for structural work and
trimmings. The Chapel of the University Avenue Methodist
Church, Syracuse, N. Y., is from this stone. (See Figs. 226,
227 and 228.)

Chemung Group.—The Chemung group furnishes a few sand-
stones for local consumption. The stone as a rule is fine
grained and even textured. In color it shades from gray to
blue. Quarries have been worked at Corning in Steuben
County, Dansville in Livingston County, Elmira in Chemung

County, Jamestown in Chautauqua County, Olean in Cattaraugus County and Waverly in Tioga County.

Triassic.—The red sandstones of Triassic age have been quarried largely for local use in Haverstraw and Nyack, Rockland County.

North Carolina.—This state quarries Triassic sandstones of fine grained even texture and of gray, brown, reddish brown and red colors. The Wadsborough dark brown sandstone that has been used for structural purposes in Washington is per-
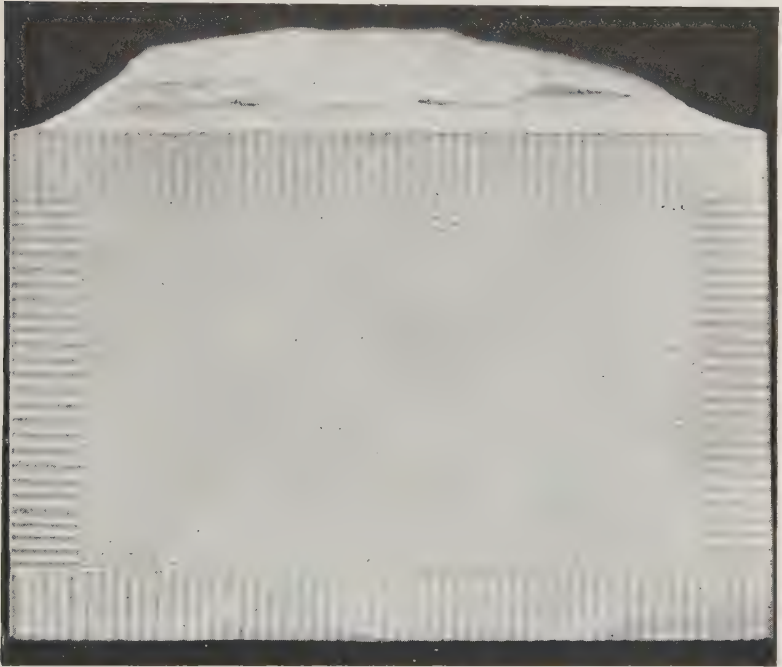
Fig. 228.—Dressed block of Warsaw bluestone, Warsaw, New York, showing margin of drove work. Photo. by C. H. Richardson.

haps the best known of the sandstones of the state. (See Fig. 229.)

Ohio.—According to E. Orton the Berea sandstone is a very fine grained, even textured and evenly bedded stone of gray, bluish gray and buff colors. Slabs 150 feet in length, 5 feet in width and only 3 inches in thickness are reported to have been raised intact from the quarry floor. The stone bears but little cementing material. It consists of grains of sand held

together by cohesion induced by the pressure to which they were subjected at the time of their consolidation. The Buena Vista sandstone in the southern part of the state is also important.

Euclid Bluestone.—This stone is extensively quarried at Euclid and Newburgh, Cuyahoga County. It is of finer grain and of more compact structure than the Berea grit. It is of brown color near the surface due to the oxidation of an iron content but a dark bluish gray color beneath the surface.

Oregon.—A fine grained, dark bluish gray sandstone is quarried near Oakland in Douglas County and a fine grained sandstone near Portland in Clackamas County. These stones are used largely for structural and paving purposes in many cities within the state.

Fig. 229.—Block of reddish brown sandstone, Sanford, North Carolina. Photo. by C. H. Richardson.

Pennsylvania.—According to T. C. Hopkins the Triassic brownstones of Pennsylvania so far as they are commercially developed are confined to the eastern and southeastern part of the state. The New Red area in which most of the productive quarries are located extends from the Delaware River north of Trenton in an irregular and broad belt west-southwest through Bucks, Montgomery, Berks, Chester, Lebanon, Lancaster, Dauphin, York and Adams Counties. Many other less productive sections are known. The sandstones were deposited in a comparatively narrow lake, bay, or arm of the

sea, which in a general way was parallel to the present coast line, and limited by the older rocks on either side. The sandstones are associated with a coarse conglomerate which was deposited by rapid streams or currents, and shales which were formed in comparatively quiet waters. The sandstones are intermediate between the conglomerate and the shale.

Hummelstown.—The Hummelstown brownstone is the best known and most extensively quarried sandstone within the state. The strike of the formation is east and west and the dip of the beds 45 degrees to the north. The separate layers vary from 20 inches to 20 feet or more in thickness. The depth of the whole formation is several thousand feet. The quarries often present a thickness of 50 feet of good brownstone.

The texture of the brownstone is fine grained and even with a greater uniformity in texture and color than any other brownstone in the United States. Hopkins states that the texture is so close and the grains so fine that the stone takes a very smooth finish. One quarry produces a purplish brown while all the others produce a reddish brown stone of brighter and warmer shade than the average New England brownstone. The stone consists of fine angular quartz grains in a cement of clay and iron oxide, and is one of the most durable brownstones of the world. (See Fig. 230.)

Mauch Chunk.—There is a belt of red shale and quartzite that stretches from the Susquehanna River in a northeasterly direction to Mauch Chunk and Scranton that has furnished a few sandstone quarries whose products have found local uses.

South Dakota.—According to N. H. Winchell the Sioux Falls quartzite is a fine grained, even textured stone of pink and red colors that receives a high polish and is equally well adapted for structural and ornamental work. Mineralogically considered the stone consists of quartz grains with a cement of silica, and only enough iron oxides present to impart the characteristic colors. It is practically impervious to moisture as the interstices between the sand grains have been completely filled by the cement. Its compression test is very high for arenaceous rocks, 25,000 pounds to the inch. The stone is represented in the buildings of Grinnell College, Grinnell, Iowa, and in the German-American Bank and Union Depot at Saint Paul, Minnesota.

Tennessee.—This state produces a coarse grained gray sandstone at Parksville and a coarse grained buff and pink sandstone at Sewanee.

Fig. 230.—Pottier and Stymus building, New York City, showing the use of Hummelstown brownstone in brownstone fronts (entire front of dressed brownstone). Photo by T. C. Hopkins.

Texas.—According to W. B. Phillips excellent sandstones occur in many counties in Texas. They are especially abundant in Bexar, Burnet, Lampasas, Lavaca, Tyler and Ward Counties.

One of the best gray sandstones in the state occurs on both sides of the Colorado River at Chaddick's Mills in Lampasas County. The most of the sandstones of Texas are of clear gray color. Near Barstow in Ward County there is a good quarry of a reddish brown sandstone that has been used to a considerable extent. One of the more recent buildings to em-

Fig. 231.—Red sandstone quarry near Barstow, Ward County, Texas. By courtesy of W. B. Phillips.

ploy this stone is the Bexar County Courthouse, San Antonio, Texas. (See Fig. 231.)

Utah.—The Triassic red sandstones of Red Butte are quarried to some extent and used for structural purposes in Salt Lake City.

Virginia.—The Triassic sandstones of Maryland extend southward into Virginia and have been quarried to some extent near Manassas. Near Acquia Creek Juro-Cretaceous sandstones have been quarried for some of the public buildings in Washington, D. C.

Washington.—According to W. F. Geiger the High School Building of Seattle represents a fine grained, even textured dark colored sandstone that is very pleasing in its decorative effect. The sandstone quarried on Chuchanut Bay is fine grained, even textured, and of bluish gray color. It is represented in the United States Custom House at Portland, Oregon.

West Virginia.—According to E. Orton the commercial sandstones of the state are of Devonian age, fine texture, and bluish gray color.

Wisconsin.—The St. Croix sandstone occurs in a curved belt that stretches from the St. Croix River in a northeasterly direction to Menominee. The stone varies in texture from fine grained to coarse, and in color it is white, grayish white and light buff.

The St. Peters formation south and west of the Menominee River is of medium and coarse texture, and of white, yellow, brown and red colors. (See Fig. 232.)

Fig. 232.—Port Wing brown sandstone, Port Wing, Wisconsin. Photo. by C. H. Richardson.

FOREIGN SANDSTONES

Austria-Hungary.—According to J. A. Howe Devonian sandstones are quarried at Trembola, Galicia, and Sternberg in Mahren. Permian and Cretaceous sandstones are quarried in Bohemia.

Belgium.—Devonian sandstones are quarried at Hainault, Yvoir, Gembloux and Wepion. Carboniferous sandstones are obtained from the Ardennes and Triassic sandstones at Luxembourg.

British Columbia.—Nanaimo has furnished Cretaceous sandstones for buildings in Victoria, and New Castle Island provided the brownish gray sandstone used in the construction of the United States Mint at San Francisco.

England.—Devonian sandstones occur at Devon and Cornwall in the beds of the Old Red Sandstone series. The stone is used for building purposes and road metal. The Carbon-
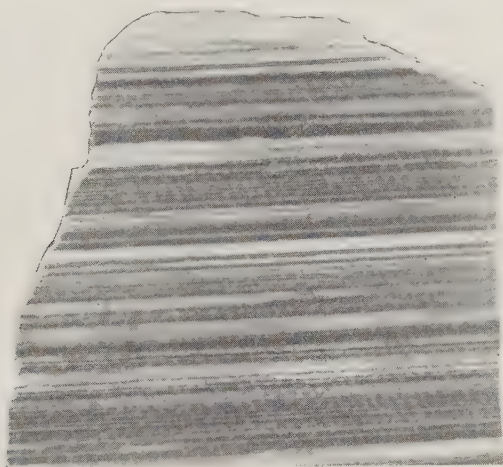
Fig. 233.—Sawn slab of banded jasper, Rhine Valley, Germany. Photo. by C. H. Richardson.

iferous Millstone Grits in the western part of England attain a thickness of 400 to 500 feet and furnish many fine grained sandstones for structural work. The Observatory and Wesleyan Memorial Hall at Edinburgh are from the Northumberland quarries.

Ireland.—According to J. Watson the Carboniferous sandstones of Ireland are the most important from a commercial standpoint. They are of even texture and in color they are white, yellow, red and purple. The Shamrock sandstone is gray in color and takes a fine finish. It is much utilized as a building stone.

France.—According to J. A. Howe sandstones of varied

texture and color are quarried in the Silurian, Carboniferous, Permian, Triassic, Cretaceous and Miocene formations.

Germany.—According to J. Watson the picturesque crags of the Saxon Switzerland, forming the great gorge of the Elbe, furnish upper Cretaceous sandstones of fine grain and yellowish drab color that are extensively used for building purposes in Silesia. Triassic sandstones are quarried in Wendelstein, Zeil, Heilbronn and elsewhere. Permian sandstones are quarried at Eggenstedt, Saxony, and Liassic sandstones in Franconia. (See Fig. 233.)

Fig. 234—Dougherty quarry in Oneida conglomerate, Frankfort Hill, near Utica, New York. Photo. by M. C. Collister.

India.—The valley of the Ganges furnishes many fine grained, even textured sandstones from the Vindhyan formations. The prevailing colors are gray, yellow, yellowish red and red. They are represented in many of the finest buildings of India. It is equally adapted for pierced work and delicate carving.

New Brunswick.—The finest sandstones of New Brunswick are of Lower Carboniferous age and occur abundantly in Albert and Westmoreland Counties. These stones are of fine grain and even texture. They are of light gray, yellow, red and olive green color. They work easily and have been im-

ported into the United States to a considerable extent for structural work.

Nova Scotia.—The sandstones of Nova Scotia near the head of Pictou Harbor are also of the same age as those in New Brunswick and possess the same general characteristics. They are not, however, so extensively quarried and imported into the United States. Bright red sandstones occur near the head of the Bay of Fundy.

Ontario.—A fine grained, even textured sandstone of Potsdam age is quarried on Vert Island in the northern part of
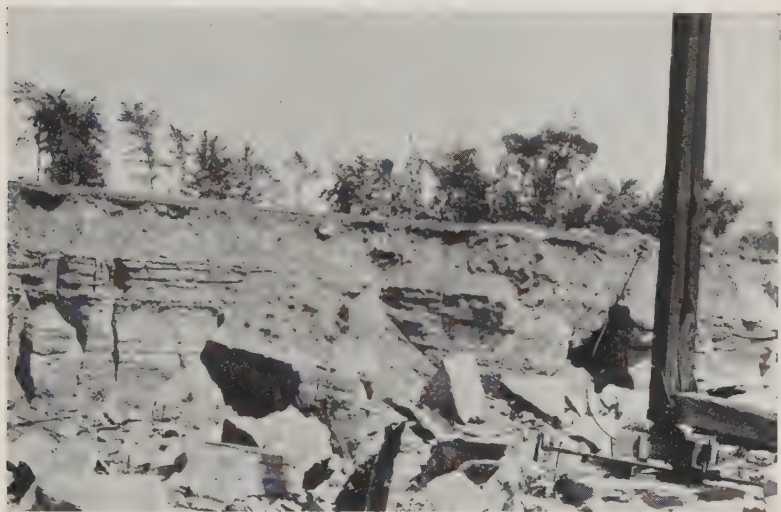
Fig. 235.—Rogers quarry, Cobleskill, New York, showing the sandstone beds and the thickness of the glacial till. Photo. by J. F. France.

Lake Superior. The stone is of bright reddish brown color and occurs in inexhaustible quantities. The mineralogical content of the stone consists of quartz, and feldspar, with a few scales of mica, and a cement of the oxides of iron.

Quebec.—Ordovician sandstones occur at Point Levis; they are of fine grain, grayish green color and durable.

Scotland.—The Devonian old red sandstones occupy large tracts in Scotland. They present a wide variety of texture and color. They are largely used for structural and paving purposes. One peculiar variety is described by R. I. Murchison as follows: "The Flagstones of Caithness are in many

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places impregnated with bitumen, chiefly resulting from the vast quantity of fishes embedded in them. The most durable and best qualities of flagstone are derived from an admixture of this bitumen, with finely laminated, siliceous, calcareous, and argillaceous particles, the whole forming a natural cement

Fig. 236.—Quarry of the American Bluestone Company, Warsaw, New York, showing fractures in the west wall of the quarry and thickness of benches. Photo. by W. A. Sargent.

more impervious to moisture than any stone with which I am acquainted."

Craigleith Sandstone.—The Craigleith sandstone has been extensively quarried for many years about 3 miles from the city of Edinburgh. It is fine grained, even textured, and of grayish drab color. The British Museum and the Bank of

England in London show the adaptability of this stone for structural work.

Hailes Sandstone.—This sandstone has been extremely popular in Edinburgh for structural work. This stone is also of fine grade and shows three distinct colors, white, pink and blue.

Triassic.—The Triassic rocks of Scotland furnish at Dumfriesshire a medium grained, bright red sandstone that is imported somewhat into the United States for structural work.

Fig. 237.—Quarry in brownstone, Hummelstown, Pennsylvania. Photo. by T. C. Hopkins.

The Corncockle quarries from Dumfriesshire furnish a fine grained, even textured sandstone of light terra cotta red color. The Gatelaw Bridge quarries produce a bright red sandstone that has also been extensively imported. The Corsehill quarries near Annan have been extensively operated and their products shippd to the United States as ballast by vessels sailing from Carlisle, England, and commercially recognized as Carlisle sandstones.

South Africa.—The famous Rosetta stone takes its name from the district of Rosetta, where most of the quarries are situated. It is fine grained, even textured, and of greenish

gray color. It is extremely popular with architects of Natal as a structural and decorative stone. The Rosetta stone belongs to the Ecca formations which are of Permian age.

Triassic.—The Forest sandstone of Rhodesia, according to F. P. Mennell is extensively developed and quarried in the Province. The stone is fine grained and presents two varieties of color. One is a rich salmon tint and the other a delicate pink color.

INDUSTRIAL FACTS ABOUT SANDSTONES

Quarrying Sandstones.—The method used in quarrying

Fig. 238.—Mill and yard of the Clark-Conroy Company, Norwich, New York. By courtesy of the Clark-Conroy Company.

sandstones depends somewhat upon the character of the joint planes and the thickness of the beds. In thin bedded sandstones that adhere feebly to the underlying sheets blocks of the desired size may be obtained with drills and wedges. In some instances the channelling machine is used to cut vertical channels in the various beds as has already been described in the quarrying of marbles. Where the blocks are thick bedded holes are sometimes drilled 10 inches in diameter and 20 feet deep. About 50 pounds of powder in an oval tin canister with

unsoldered edges and ends covered with paper or cloth is lowered into the hole and placed so that a plane passing through its edges is in the direction of the desired break and then fired. The loosened blocks are then split into smaller dimensions by wedges.

The Knox system consists essentially of making a series of elongated holes along the line of the desired break, putting in a light charge of powder, leaving an air chamber between the powder and the confining plug, and firing all simultaneously with an electric battery. It requires a special reamer for the elongation of the drill hole.

Fig. 239.—Dimension blocks of sandstone from Rogers quarry, Cobleskill, New York, designed for constructional work in New York City. Photo. by C. H. Richardson.

The Lewis system consists of drilling two holes about half an inch apart, cutting out the rock between the two holes, filling with powder and blasting in the same manner as in the Knox system.

The Githens system drills the hole with a single drill in the oval shape desired. The stone is then blasted as in the preceding systems.

Whatever the system of blasting may be there is always some danger of loss of material through fractures induced by blasting. The heavier the charges of powder used the greater this danger becomes. Sometimes these planes are not noticed

until the stone is dressed, or even set in its bed in structural work, yet in all cases such fractures are lines for the invasion of moisture and the stone disintegrates or crumbles. The less jar a sandstone receives from heavy hammers the greater will be its durability. (See Figs. 234, 235, 236, 237, 238 and 239.)

Uses.—W. C. Day in the Stone Industry of 1894 gives the following summary of the uses of sandstones:

Foundations, Superstructures and Trimmings.

Solid fronts, foundations, cellar walls, underpinning, steps, buttresses, window sills, lintels, kiln stone, capping, belting or belt courses, rubble, ashlar, forts, dimensions, sills.

Street Work.

Paving blocks, curbing, flagging, basin heads or catchbasin covers, stepping stones, road-making, macadam, telford, concrete, sledged stone, crushed stone.

Abrasive Purposes.

Grindstones, whetstones, oilstones, shoe rubbers.

Bridge, Dam and Railroad Work.

Bridges, culverts, aqueducts, dams, wharf stone, breakwaters, jetties, piers, buttresses, capstone, rails, ballast, approaches, towers, bankstone, parapets, docks, bridge covering, bridge guards.

Miscellaneous.

Grout, hitching posts, fence wall, sand for glass, sand for cement, sand for plaster, furnace hearths, lining for blast furnaces, rolling-mill furnaces, lining for steel converters, fire brick, silica brick, core sand for foundries, adamantine plaster, cemetery work, millstones, fluxing, ganister, glass furnace, random stock.

Compression Tests.—The compressive strength of sandstones varies widely. Some sandstones are extremely friable and with insufficient resistance to be used for structural purposes while others like the metamorphic member quartzite are superior in strength to most of the granites. A few of the tests from widely scattered localities are appended for reference.

		Lbs. Per Sq. In.
1.	San Jose, California	2,400
2.	Haverstraw, New York	4,350
3.	Riverside, Indiana	6,800
4.	Annan, Scotland	7,925
5.	Berea, Ohio	10,250
6.	Edinburgh, Scotland	12,000
7.	East Longmeadow, Massachusetts	12,210

8. Kettle River, Minnesota 12,580
9. Albion, New York 13,500
10. Hummelstown, Pennsylvania 13,610
11. Medina, New York 17,250
12. Warsaw, New York 19,022
13. Quartzite, Sioux Falls, South Dakota.........25,000
14. Quartzite, Pipestone, Minnesota....................27,750

Analyses.—A few analyses of well known sandstones are here given as a matter of reference.

1. Warsaw, New York, bluestone.

Silica, SiO_2 ....76.50%
Alumina, Al_2O_3 ....14.75
Ferric oxide, Fe_2O_3 ....6.35
Water, H_2O 2.00
                                                                    ――――
                                                                    99.60

2. Hummelstown, Pennsylvania, brownstone.

Silica, SiO_2..90.34
Alumina, Al_2O_3..4.35
Ferric oxide, Fe_2O_3..1.09
Lime, CaO 0.95
Magnesia, MgO 0.17
Potash, K_2O 1.30
Soda, Na_2O 0.19
Water, H_2O 0.61
                                                                    ――――
                                                                    99.00

3. Riverside, Indiana.

Silica, SiO_2 ....93.16
Alumina, Al_2O_3 ....1.60
Ferric oxide, Fe_2O_3 ....2.69
Lime, CaO 0.13
                                                                    ――――
                                                                    97.58

4. Red sandstone, Barstow, Texas.

Silica, SiO_2 ....70.00
Alumina, Al_2O_3 ....7.50
Ferric oxide, Fe_2O_3 ....3.00
Lime, CaO 8.00
Magnesia, MgO 0.30
Soda, Na_2O 2.00
Potash, K_2O 2.50
Carbonic acid, CO_2 ....6.00
Water, H_2O 0.40
                                                                    ――――
                                                                    99.70

5. Craigleith stone, Edinburgh, Scotland.

Silica, SiO_2 .... 98.30
Alumina and ferric oxide, Al_2O_3 and Fe_2O_3.... 0.60
Calcium carbonate, $CaCO_3$ 1.10
                                                                                    ———
                                                                                    100.00

6. Red Wilderness Sandstone, Gloucestershire, England.

Silica, SiO_2 .... 88.70
Alumina, Al_2O_3 .... 3.25
Ferric oxide, Fe_2O_3 .... 1.80
Ferrous oxide, FeO 0.30
Manganous oxide, MnO.. 0.10
Lime, CaO .... 2.90 .
Magnesia, MgO 0.11
Soda, Na_2O 0.31
Carbon dioxide, CO_2 .... 1.94
Water, H_2O 0.59
                                                                                    ———
                                                                                    100.00

TABLE SHOWING THE SPECIFIC GRAVITY; STRENGTH PER SQUARE INCH; WEIGHT PER CUBIC FOOT, and RATIO OF ABSORPTION OF SANDSTONES.

Kind and Locality	Size of Cube, Inches	Position	Lb. Strength per Sq. In.	Specific Gravity	Lb. Weight per Cu.Ft.	Ratio of Absorption	Remarks
Sandstone, Gunnison, Gunnison Co. (Rhyolite tuff)	2.02x2.02	Bed	6,127	2.066	128.877	1/146	Broke suddenly into irregular pieces.
Sandstone, ...	2.00x2.01	Edge	5,224	2.233	139.294	1/120	Broke suddenly into small fragments.
Sandstone, Manitou, El Paso Co., Colo...	1.97x2.03	Bed	9,250				
	2.01x1.96	Edge	10,152				
Sandstone, Glencoe, Jefferson Co., Colo...	2.00x2.02	Bed	12,752				Snapped suddenly into small pieces and dust.
	2.02x2.02	Edge	10,778				
Sandstone, Walsenburg, Huerfano Co., Colo.	2.00x2.03	Bed	5,571	2.360	148.5	1/40	Crushed into small pieces and sand.
	2.01x2.02	Edge	5,261				
Sandstone, Portland, Conn.	..	Bed	13,310				
Sandstone, Cromwell, Conn.	..	Bed	12,582				
Sandstone East Long Meadow, Mass.	..	Bed	8,812	2.385	142.8	1/32	Average of two trials.
	..	Edge	6,165	2.285	142.8	1/32	
Sandstone, Marquette, Mich.	2	Bed	5,550	2.529	139.3	1/17	
Sandstone, Hinckley, Minn	2	Bed	19,000	2.221	138.8	1/16	
		Edge	17,500				
Sandstone, Near Ft. Snelling, Minn	2	Bed	14,250	2.729	170.6	1/366	
		Edge	20,000				
Quartzite, Pipestone, Minn.	2	Bed	27,750	2.359	141.0	1/27	
		Edge	27,000				
Sandstone, Belleville, N. J.	2	Bed	11,700	2.130	133.1	1/34	Broke suddenly.
		Edge	10,250				
Sandstone, Haverstraw, N. Y.	2	Bed	4,350	2.420	151.2	1/44	
Sandstone, Albion, N. Y.	2	Bed	13,500	2.420	151.2	1/44	
		Edge	11,350				
Sandstone, Medina, N. Y.	2	Bed	17,250	2.410	150.6	1/56	
Sandstone, Medina, N. Y.	2	Edge	14,812	2.390	149.3	1/51	
Sandstone, Cleveland, O.	2	Bed	6,800	2.240	140.0	1/37	Lilac in color, more purple than last.
Sandstone, Hummelstown, Pa.	6.45x6.40x6.04	Bed	12,810				
Sandstone, Hummelstown, Pa.	6.45x6.50x6.02	End	13,610				Burst suddenly.
Sandstone, Edinburgh (Craigleith), Scotland	2	Bed	12,000	2.360	141.3	1/34	
Sandstone, Edinburgh (Craigleith), Scotland	2	Edge	11,250	2.360	141.3	1/34	
Sandstone, Verte Island, Lake Superior...	2	....	11,342				
Sandstone, San Jose, Cal.	..	....	2,400	2.64	165.0	1/16	

REFERENCES

Becker, G. F.   Monograph XIII, U. S. Geological Survey; Origin of Concretions, Weathering, Alteration of Sandstones, 1888.

Chamberlin, T. C. Geology of Wisconsin, Volumes I and II; Madison, 1883.

Eckel, E. C.   Building Stones and Clays; Wiley and Sons, New York, 1912.

Howe, J. A.   The Geology of Building Stones; E. Arnold, London, 1910.

Hopkins, T. C.   The Carboniferous Sandstones of Western Indiana, 1896.

Hopkins, T. C.   The Building Materials of Pennsylvania Brownstones, 1896.

Hull, Edward.   A Treatise on the Building and Ornamental Stones of Great Britain and Foreign Countries; London, 1872.

Lewis, J. V.   Building Stones of New Jersey; New Jersey Geological Survey, 1908.

Merrill, F. J. H.   Building Stones of New York; Mineral Industry, Vol. III, 1894.

Merrill, G. P.   Stones for Building and Decoration; Wiley and Sons, 1891.

Ries, H.   Building Stones and Clay Products; Wiley and Sons, 1912.

Smock, J. C.   Building Stone in the State of New York; Bulletin III, New York State Museum, 1888.

Smock, J. C.   Building Stone in New York; Bulletin X, New York State Museum, 1890.

Watson, J.   Building Stones; Cambridge University Press, 1911.

Winchell, N. H.   Building Stones; Geology of Minnesota, Vol. 1, Minneapolis, 1884.

Zirkel, Ferdinand.   Lehrbuch der Petrographie, 2nd Edition, Vol. III, 1894.

CHAPTER VI

SHALE AND SLATE
SHALE

Definition.—A shale is a consolidated mud or clay in which the silicates of aluminum are the most important and characteristic constituents. In texture it is fine grained. In structure it is laminated or fissile. The term shale has been used to embrace a wide variety of sedimentaries that present a shaly structure. Sand grains by wave action may be reduced to an impalpable powder and these consolidated flourlike particles may present a shaly appearance. In the presence of clayey matter such rocks pass into argillaceous sandstones. Grains of calcite may be rendered correspondingly minute and consolidated into a shaly rock. In the presence of clayey matter the stone is best classified as an argillaceous limestone.

Varieties.—Many varieties arise from the different types of detritus from which the shale is derived. True shales pass on the one hand by insensible gradations into unconsolidated clay beds and on the other into a fissile slate. The arenaceous and calcareous shales have already been mentioned. Carbonaceous shales are often associated with the coal measures and bear a conspicuous coaly content. A bituminous shale is one rich in volatile hydrocarbons and from which various oils are often distilled. A pyritic shale is one containing pyrite or marcasite. An alum shale is one bearing soluble sulphates that result from the oxidation of the pyrites in a pyritic shale. A kaolinitic shale is one that contains kaolinite. According to W. M. Hutchins kaolinite is present only in small quantities in some of the Carboniferous clays and shales. A micaceous shale bears scales of mica that were deposited along with the other sediments from which the shale was derived. The occurrence of the brittle micaceous mineral, chlorite, derived from the debris of ferromagnesian minerals, gives rise to a chloritic shale.

Cements.—Cementation is a subordinate factor in the formation of shales. The coherence of shale is due mainly to the pressure that has been exerted upon the colloidal particles contained in the mud and clays, whose consolidation produced shales. According to C. R. Van Hise the spaces amongst the individual particles is reduced to a minimum and the porosity of the stone

is correspondingly low. In this respect shales bear a striking contrast with sandstones, where the interstitial spaces exceed 24 per cent. By pressure the water of the muds is largely expelled so that the resulting shale bears less ground water than the original clay or mud and is more hydrous than slate. There are however exceptions for the analysis of the bituminous shale of Dry Gap, Georgia, as made by L. G. Eakins, shows a lower water content than the black slate of Slatington, Pennsylvania.

Uses.—Shales are too soft and friable for structural work. They are not sufficiently fissile for roofing purposes. They are utilized to some extent as road metal. The more compact forms have found use for sidewalks and curbing. Some varieties are used in the manufacture of cement and bricks. The ferruginous shale near Mauch Chunk, Pennsylvania, is ground and used as a pigment. Bituminous shale is a source of many oils. Shaly coal may serve as an unsatisfactory fuel.

Analysis.—The following represents a composite analysis of 51 Paleozoic shales, by H. N. Stokes.

Silica, SiO_2	60.15
Titanium oxide, TiO_2	0.76
Alumina, Al_2O_3	16.45
Ferric oxide, Fe_2O_3	4.04
Ferrous oxide, FeO	2.90
Manganous oxide, MnO	Trace
Lime, CaO	1.41
Barium oxide, BaO	0.04
Magnesia, MgO	2.32
Soda, Na_2O	1.01
Potash, K_2O	3.60
Lithia, Li_2O	Trace
Water, $H_2O + 110°F$	3.82
Water, $H_2O - 110°F$	0.89
Phosphorus pentoxide, P_2O_5	0.15
Carbon dioxide, CO_2	1.46
Sulphur dioxide, SO_2	0.58
Carbon, C	0.88

100.46

SLATE

Definition.—Geologically considered, a slate is a metamorphosed clay or shale. It may or may not have paused at the shale phase. Commercially a slate denotes a rock which pos-

sesses fairly perfect cleavage, adapting it to commercial uses for which other types of building stones are not well suited. In either case, with few exceptions, its mineral composition can be distinguished only with the aid of the microscope. It differs from a shale, in that it has perfect cleavage and has been subjected to a considerable amount of pressure. Furthermore a slate is somewhat richer in silica and ferrous oxide than a shale. This also implies that a slate has been subjected to different processes of metamorphism or else to further processes than a shale. It differs from a schist in that the slate is the more fissile, consists of finer particles and does not possess the wavy structure that is characteristic of the latter rocks. Shales, slates and schists may have originated in deposits of nearly identical character but they have undergone different processes. By metamorphism a slate passes into a schist.

Origin.—The vast majority of commercial slates are of sedimentary origin. Fine grained homogeneous sediments of clayey composition have been subjected to pressure sufficiently intense to develop the characteristic cleavage of slates. The finest of detritus was deposited in comparatively quiet waters. When such material consolidates under normal conditions a shale results. Such a rock breaks into irregular blocks because it does not possess the cleavage system of slates. When such rocks are subjected to crustal movements that exert heavy pressure or long continued pressure certain important physical changes are induced which are more important in slates than the accompanying chemical changes. The sediments must be fairly homogeneous for it is obvious that the fissility of slates can not be induced in a heterogeneous material. The material must not be rich in sand for sand beds do not possess the requisite plasticity for slates. Neither do highly calcareous deposits possess this property of plasticity. Such sedimentaries must possess also a uniformity of chemical composition. That such is the case is readily shown by consulting a wide variety of chemical analyses of roofing slates.

Igneous Origin.—A few slates are of igneous origin. Even here there are two widely different modes of formation. (1) Slates formed by the consolidation of volcanic ash. These ash beds must have been subjected to pressure sufficient to induce the slaty cleavage. The green slates of the Lake District, England, are of this origin. (2) Slates formed by the shearing of igneous rocks. The green slates near Placerville, California, are of this type. They appear as narrow bands extending from

the top to the bottom of the quarry wall while the main mass of the quarry wall is a glossy black slate of sedimentary origin.

Composition.—As has already been noted the chemical composition of roofing slates is fairly constant. This holds true of all slates of sedimentary origin. The total silica and alumina content of 47 analyzed samples was 78.76 per cent. Total iron oxides, 7.40 per cent. Total lime and magnesia, .05 per cent. Total alkalies, 4.47 per cent. Total water and carbon dioxide, 5.60 per cent. A large part of this water is chemically combined and the lime is present as a carbonate which often serves as a cement. The average composition of igneous slates differs somewhat from the above analyses. They are generally lower in their silica content and average higher in alumina as will be seen in the analyses of slate cited later in this chapter.

Mineralogical Composition.—This is an important factor in the estimation of the durability of roofing slate, and therefore their commercial significance. If homogeneous clayey matter is compressed by weight or pressure and cemented by the carbonates of lime and magnesia, or by kaolin, or varying compounds of iron, their cleavage, strength and elasticity are low. If by metamorphism the kaolin and feldspathic particles have been transformed into scales and overlapping fibers of mica their fissility, strength and elasticity are correspondingly high. The former are called clay slates and the latter mica slates. The slate of Martinsburg, West Virginia, is a clay slate while the purplish slate of Fair Haven, Vermont, is a mica slate.

Minerals of Slates.—T. N. Dale in Bulletin 275 of the U. S. Geological Survey gives the following classification of the minerals of slates.

Clastic minerals: quartz grains, feldspar grains, zircon grains, muscovite scales, kaolin, magnetite, granular carbonates. Clastic or authigenous minerals: rutile needles, tourmaline. Authigenous minerals: chalcedonic quartz, vein quartz. muscovite (sericite), biotite, chlorite, pyrite, magnetite, hematite, calcite, magnesite, siderite, rhodochrosite, andalusite, barite, gypsum, talc. Organic minerals: carbonaceous matter.

Classification.—Origin may be made the basis of classification. Slates then fall into (1) Aqueous sedimentary, (2) Igneous. The first may be subdivided into (A) Clay slates (B) Mica slates. The latter class may be subdivided upon the permanency of color into (1) Fading slates which bear a sufficient amount of siderite to cause discoloration upon prolonged exposure to the corrosive agents of the atmosphere. Some slates bearing carbonaceous matter or graphite, others bearing chlorite, or hematite and

chlorite fall into this class. (2) Unfading slates. These do not discolor materially upon prolonged exposure. These are graphitic, hematitic, chloritic, or hematitic and chloritic. The slates of igneous origin are further subdivided into ash slates and dike slates.

Impurities.—The objectionable impurities are often calcite, magnesite, dolomite, siderite, rhodochrosite, pyrite, magnetite, andalusite, staurolite and garnet. Calcite is an element of weakness in a slate as well as in a sandstone. Siderite causes a slate to fade. The decomposition of rhodochrosite supplies the black oxide of manganese. The last five minerals in the list cited are much harder than the slate and tend to gapple the machinery

Fig. 240.—White quartz veins in closely folded and faulted slate, Coventry, Vermont. Photo. by C. H. Richardson.

used in cutting slate. The cleavage is around the minerals rather than across them. Inequalities of surfaces result from their presence. (See Fig. 240.)

Color.—The prevailing colors in slates are black, gray, green, red, purple and spotted. The black color is due to carbonaceous matter derived from various marine organisms suffering decomposition on the floor of the sea where the sediments were deposited. The green slates owe their color to the chloritization of micaceous scales deposited with the original muds from which the slate was derived, or possibly in the case of igneous slates to the metamorphism of hornblende. The red slates owe their color

to the dehydration of limonite and the purplish slates to the presence of both hematite and chlorite. The spotted slates owe their spots to the reduction of ferric oxide to ferrous oxide through the agency of decaying organisms and the removal of the ferrous compound either as an organic salt or carbonate. Such patches are usually richer in calcite, siderite, rhodochrosite, silica, and pyrite. They are less resistant to decomposition than slates of uniform color. (See Fig. 9.)

Importance of Color.—It is obvious that slates for roofing purposes should be of uniform color and permanent. If they fade at all as many slates do the fading should be uniform. Bluish slates often turn gray and red slates may become brown upon prolonged exposure. Green slates are the most unreliable for they bear decomposable carbonates, and limonite is one of the products of such decomposition. The oxidation of grains of pyrite and marcasite produces unsightly blotches. Building specifications cite colors as well as sizes and new colors are hard to introduce.

Structure.—Bedding and cleavage are two important factors in the slate industry. The bedding planes were approximately parallel with the sea floor on which the sediments were deposited. The beds may be thick or thin. They may alternate with arenaceous or calcareous beds. They may be uniform or of different colors. They are the starting point in a slate quarry and indicate where slates of a uniform grade may be encountered.

Cleavage.—The cleavage in slates is somewhat analogous to the gneissoid lamination in certain granitic rocks. It is due to the intense pressure to which the rock mass has been subjected, to the orientation of unequiaxed particles in the original sediments and to the development of new minerals by chemical and mineralogical processes. The cleavage may conform with the original bedding planes, in which case the split surface will be rough, or it may diverge at any angle from the bedding planes. E. C. Eckel considers this divergence in the majority of commercial slates as very small. The lowest angle noted by T. N. Dale in the slates of Pennsylvania was from 5 to 10 degrees and in western Vermont and eastern New York 20 degrees. In one quarry in central Vermont, as observed by the author, it was 35 degrees.

There is also a slip cleavage that must not be confused with the true slaty cleavage. The former is called a false cleavage or bate by the quarrymen. It is subsequent in origin to the slaty cleavage and may be developed in one or more than one system

of movements. The true cleavage pervades the entire mass and is visible in each fragment.

Texture.—The texture of slates varies widely. Some of them are very fine, some fine, some medium, while others are coarse. For mill stock a slate should be fine grained, rather than coarse, even textured rather than varied, soft rather than hard, and of uniform rather than different colors. In roofing slate durability and strength are desired. Uniformity and permanency of color are sought. Such slates should not fracture in punching the nail holes.

Specific Gravity.—The specific gravity of roofing slates varies from 2.71 for the slate of Raceville, New York, to 2.81 for the Delabole, Cornwall, England, slate.

Transverse Strength.—This is given as modulus of rupture in pounds per square inch. It varies from 7,150 pounds for the Albion quarry, Pen Argyl, Pennsylvania, to 11,250 pounds for the Peach Bottom slates of Pennsylvania and Maryland.

AMERICAN SLATES

Arizona.—Near Phoenix, Arizona, there is a belt of bluish gray slate which is approximately one mile in length and 1,000 feet across the formation. It has a fair degree of fissility and bears pyrite, clayey matter, and a little magnetite.

Arkansas.—The slate belt in this state extends from near Little Rock in a westerly direction for about 100 miles. Its maximum breadth is 20 miles. E. R. Buckley gives the following geological section of the area:

Quartzite and sandstone	200 feet
Red slate	300 feet
Quartzite and sandstone	500 feet
Black slate	400 feet

Workable roofing slates constitute only a small portion of the section. Good roofing slates are obtained near Hot Springs, Garland County; and in Montgomery and Polk Counties fine grained, even textured slates of gray, black, red and greenish colors are manufactured. These slates are of Ordovician age.

California.—According to E. C. Eckel the Mariposa slates cover a large area in Eldorado County. Their general strike is north 15 degrees west. They are of late Jurassic or early Cretaceous age. The main mass of the Eureka quarry product is a dense, deep black slate, splitting very finely and regularly, with a smooth glistening surface much like that of the Bangor and Lehigh slates of Pennsylvania. The frequency of ribbons

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and pyrite nodules prevents the slate from being serviceable as mill stock, but as roofing material it is excellent.

The Eureka quarry green slate is of igneous origin. It was probably derived from a gabbro or similar rock. Eckel states that a band of green slate several feet wide crosses the Eureka quarry. That on examination he found that the borders of the band were not parallel to the ribbon structure of the black slate. The green band can not, therefore, be interbedded with the black slates. The probability that it represents a dike of compact igneous rock which has been changed to slate by pressure subsequent to its intrusion is strengthened when the chemical composition of the green slate is considered. The analysis will be given with others at the end of the chapter. The Eureka quarries have shipped their products to Hawaii and the Island of Guam while the slates of this county have no competitor in the markets on or near the Pacific coast.

Georgia.—The most extensive slate quarries in the United States south of Pennsylvania are located at Rockmart, Georgia. According to C. W. Hayes the Rockmart slate is of Ordovician age. The formation which now produces roofing slate was originally a fine grained homogeneous clay shale. Under the influence of metamorphism, connected probably with the extensive faulting which the region has undergone, a very perfect cleavage was developed, which generally obscures and in some cases obliterates the original bedding. Along the Cartersville fault the slate near the fault is wrinkled so that it does not cleave readily, and at a considerable distance from the fault the cleavage is only imperfectly developed. Therefore, the best slates are encountered within a comparatively narrow area from one to five miles from the fault.

The better grade of material is a black roofing slate. The product commands a good price. The Southern States Portland Cement Company is located about half a mile east of Rockmart, Georgia. This company is using the poorer grades of slate that with many companies becomes waste in the manufacture of Portland cement. The products used are a mixture of slate and limestone.

Maine.—Commercial slates are found in Maine in Piscataquis County which is located near the center of the state. The quarries are both to the east and to the west of Sebec Lake in the towns of Blanchard, Brownville and Monson. According to C. H. Hitchcock the slate formations are of Paleozoic age. The belt is from 15 to 20 miles in width and strikes in a northeasterly direction.

Blanchard.—The quarries of the Lowell Slate Company are situated at North Blanchard, Maine. The Blanchard quarry is 300 feet long, 50 feet wide and 200 feet deep. The slate beds alternate with quartzites. The slate is a very dark gray. It is of fine grained, even texture and slightly lustrous. It is used for roofing, mill stock and electrical appliances.

Brownville.—The quarry of the Merrill Brownstone Slate Company is situated less than a mile from Brownville station and to the west of Pleasant River. According to T. N. Dale there are in this quarry 42 beds of slate alternating with as many beds of quartzite. The total thickness of these beds is

Fig. 241.—Merrill slate quarry, Brownville, Maine. The end wall working face has 42 beds of slate alternating with quartzite. By courtesy of the U. S. Geological Survey.

165 feet. At the Hughes quarry which is operated by the same company and is situated about a mile northwest of the Merrill quarry there are 28 beds of slate alternating with as many beds of quartzite. The total thickness here is 161 feet 6 inches. These slates are very dark gray in color. They are fine grained, even textured and with bright luster. The product is used largely for roofing purposes. The presence of magnetite prevents its use for electrical appliances. (See Fig. 241.)

Monson.—The quarries of the Monson Slate Company are

about 3 miles southwest of the village of Monson, while the quarry of the Monson Consolidated Slate Company is at West Monson. The slates are of dark gray color, fine grain, even texture, free from magnetite, but they bear a little graphite and pyrite. They are used for roofing and mill stock. The absence of magnetite makes them desirable for electrical appliances.

The Forks slate quarry is in Somerset County about 18 miles west of the North Blanchard quarries. The slate is of bluish black color, fine texture, perfect cleavage and is well suited for both roofing and mill stock purposes.

Maryland.—There are two slate districts in Maryland. One lies about 30 miles northeast of Baltimore and the other about 40 miles west of Baltimore. The former is in Hartford County where the slate at Cardiff is continuous with the Peach Bottom slates of Pennsylvania. The slate is of bluish black color, fine grain, smooth texture, tough and non-fading. The second district is located in Frederick and Montgomery Counties, where quarries have been worked to some extent. This stone is also of bluish black color and good quality. The Thurston and Ijamsville quarries are the best known. They bear no magnetite and therefore are suited for electrical appliances. E. B. Mathews regards them as bearing talc to about 5 per cent.

Massachusetts.—The slate quarries at Lancaster, Worcester County, were opened about 1750. In the last century the quarrying has been intermittent. The slate is durable and essentially a roofing slate. According to N. S. Shaler a second slate district occurs in the vicinity of Boston and Cambridge. Shaler regards this stone of great value for rough building and very durable. Shepherd Memorial Church in Cambridge represents this slate. The material has also been used extensively in the manufacture of permanent roads.

Michigan.—The black slates of Michigan, quarried in Houghton, Marquette and Menominee are of pre-Cambrian age and practically inexhaustible in quantity. They are black in color of fine grain, even texture, tough, durable and therefore good roofing material. Good slates have also been quarried about 3 miles from Huron Bay.

Minnesota.—According to N. H. Winchell there is an inexhaustible supply of hard, black, and apparently durable slate in northern Minnesota, a few miles west of Duluth. Winchell regarded these slates as suitable for all uses to which slate is

normally applied. T. N. Dale regards these slates of inferior quality. They are of pre-Cambrian age.

New Hampshire.—A slate belt traverses the western part of the state in a line roughly parallel with the Connecticut River. Quarries have been operated in Hanover, Lebanon and Littleton. The product from the Hanover quarries was used for roofing and rough work. The Lebanon quarries are in the eastern part of the town. The stone has not the perfect cleavage of the Maine and Vermont slate. It sometimes bears staurolites that interfere with the splitting, trimming and planing of the slate. The stone has been used for many kinds of work and the waste product ground and bolted into slate flour. The Littleton slate has been quarried in two localities. The productive belt is about 600 feet in width, but it must not be inferred that the whole 600 feet is good roofing slate. The stone is of dark blue color and fairly fissile. Its use has been for roofing, tables, platforms, curbs and flagstones.

New Jersey.—Near Newton and Lafayette the eastern extension into New Jersey of the Bangor-Slatington slate of Pennsylvania has furnished good roofing material. The characteristics of the slate are given under the caption of Pennsylvania.

New York.—A slate belt in the extreme eastern part of the state traverses in a northeasterly direction the counties of Columbia, Dutchess, Rensselaer and Washington. The productive quarries are in Granville, Hampton and Whitehall. Greenish and purplish slates of Lower Cambrian age were once extensively quarried at Middle Granville and Jamesville on the New York side of the line, but at present these slates are almost exclusively quarried on the Vermont side of the boundary line. The Hudson River Group furnishes Ordovician slates of red and green colors. It is on the New York side that these slates reach their best development.

T. N. Dale states that the red slate is of a decidedly reddish brown color, becoming brighter on exposure. To the unaided eye its texture is fine, and its cleavage surface varies from slightly roughish to speckled with minute protuberances that are without luster. It is magnetitic, calcitic, argillaceous and sonorous. Dale gives the mineralogical composition in descending order of abundance, muscovite (sericite), quartz, hematite, calcite, chlorite, magnetite, rhodochrosite. These red slates are permanent in color. (See Fig. 242.)

The bright greenish slate is interbedded with the red slate. Its texture is much like that of the red and its green color is

attributed to chlorite. Ordovician black slates have been quarried near Hoosick and elsewhere in Rensselaer County.

Pennsylvania.—The slate producing districts of Pennsylvania are known as the Bangor-Slatington district and the Peach Bottom district. The former is located in Lehigh and Northampton Counties and the latter in Lancaster and York Counties. The former embraces a belt 32 miles long and 2 to 4 miles wide on the south side of Blue Mountain. It stretches from the Delaware Water Gap in a southwesterly direction to within 5 miles of Lehigh Gap. The exposures of slate and shale formations vary from 1,000 to 6,000 feet. These terranes
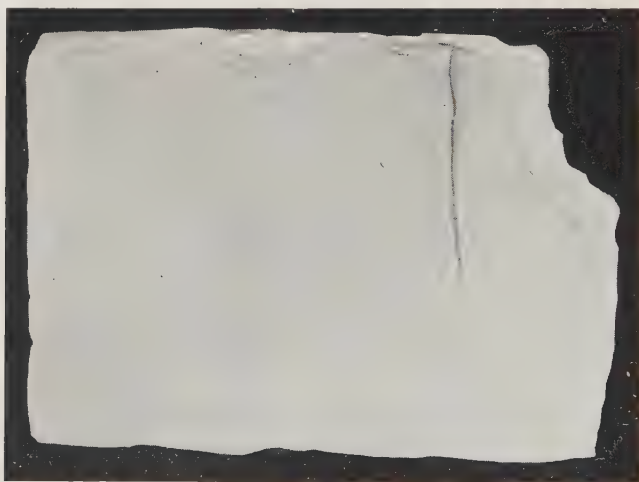
Fig. 242.—Small slab of red slate, Granville, New York. Photo. by C. H. Richardson.

are of Ordovician age but more specifically they belong to the Martinsburg shale. The more northerly and upper portions of the beds furnish the soft vein and the more southerly and lower portions supply the hard vein. The quarries at Bangor, East Bangor, Danielsville, Pen Argyl, Slatedale and Slatington are in the soft vein belt, while those of Belfast and Chapman are in the hard vein belt.

Bangor.—The Bangor quarries are 1,000 feet long, 500 feet wide and 300 feet deep. The slate is of dark gray color, of fine grain, of perfect cleavage, and without luster. It is graphitic, calcitic, argillaceous, sonorous and the sawn edge shows pyrite. The quarries at East Bangor produce a dark

Fig. 243.—Old Bangor slate quarry, Bangor, Pennsylvania, show-ing the close overturned syncline crossed by almost horizontal cleavage. By courtesy of J. S. Moyer.

Fig. 244.—Crown slate quarry, Pen Argyl, Pennsylvania. This quarry has been a large producer of roofing slate. By courtesy of the Pen Argyl Slate Company.

bluish gray slate that in all other respects is like the Bangor product. (See Fig. 243.)

Pen Argyl.—These quarries are 650 feet long, 600 feet wide and 300 feet deep. They are nearer the bottom of the soft vein than the Bangor slate. The slate is of dark gray color, of fine texture, while the cleavage surface is slightly rough and almost lusterless. It is graphitic, magnetitic and pyritic. It contains less carbonate than the slates obtained at higher altitudes on the soft vein. (See Fig. 244.)

Chapman.—The Chapman quarries are in the hard vein belt

Fig. 245.—Blue Mountain slate quarry near Slatington, Pennsylvania, showing the character of the syncline, its relation to cleavage and the southward bending of the cleavage at the surface. By courtesy of the U. S. Geological Survey.

and therefore lower down in the Ordovician formations. The quarries are about 800 feet long, 200 feet wide and 300 feet deep. The slate is of dark gray color, fine texture, roughish cleavage surface and somewhat lustrous. The amount of carbonate is small and the stone weathers well. The above quarries are all located in Northampton County.

Slatington.—The quarries in Lehigh County are confined to an area about 3 miles square, along Trout Creek and its tributaries. Some of the quarries have attained a depth of 300 feet. The Slatington slate is of dark bluish gray color, of fine grain,

even texture and nearly lusterless. There is little if any pyrite present, but the slate bears magnetite and graphite. It is also calcitic and argillaceous. (See Fig. 245.)

Peach Bottom Slate.—This belt forms a low ridge that extends from Lancaster County, Pennsylvania, through York County to Cardiff, Maryland. The belt is 10 miles long and varies in width from 1,000 to 3,000 feet. This slate is of dark gray color with a somewhat bluish tinge. Its texture is minutely granular and crystalline. It contains graphite, magnetite, pyrite and is non-calcitic. It is very sonorous and non-fading.

Tennessee.—According to C. L. Keith the slate deposits are located in the eastern part of the state. Two formations are producers. The Wilhite slate is too calcareous and soft for commercial use in the vicinity of Little Tennessee River, but it has the necessary hardness, evenness and cleavage along Little Pigeon River. Along this stream the slate is well exposed over great areas, yet the stone has not been developed on a commercial basis.

Keith cites quarries in the Pigeon slate along the Little Tennessee River at many points. Slates and flags have been quarried for local use. Quarries have been opened some two miles from the river and these quarries produce slates that are of fine grain, even texture and well suited for mill stock or roofing purposes.

Utah.—According to E. C. Eckel the Provo slates furnish green and purple varieties, the latter variety being present in the larger quantity. The green slates show less tendency to cleavage than the purple varieties and are therefore less satisfactory for roofing purposes. They rub smooth and make good slabs for mill stock. The purple slate splits well and shows a surface about as smooth as that of the Peach Bottom slate of Pennsylvania and Maryland. These slates are supposed to be of Ordovician age but may be Cambrian.

Vermont.—The author has visited every known slate quarry, whether actively operated or abandoned, in Vermont, as well as in New Hampshire and New York. The work of T. N. Dale has the greater value on account of the larger element of time and the greater detail he has given his results.

There are four distinct slate belts in Vermont which have some commercial significance.

(1) THE CONNECTICUT RIVER SLATES.—This belt appears in Guilford, in Windham County, in the extreme southeastern part of the state, and traverses northward interruptedly nearly the entire length of the state. The width of the belt varies from

100 to 1,000 feet. Its general strike is north 10 degrees east. In North Hartland, in Windsor County, it is north and south but changes in Hartford, in the same county, to north 50 degrees east. The dip changes from 60 degrees west in Hartford to 85 degrees east in Fairlee. Quarries have been worked in Guilford in Windham County, Thetford in Orange County and Waterford in Caledonia County. The slate is black or of very dark gray color. It is fine grained, medium textured and lustrous. Waterford slate splits in blocks of any dimension desired. It is graphitic and several samples have shown no effervescence with cold dilute HCl. The quarry was abandoned on account of distance from the railroad. The slate is of Ordovician age. (See Fig. 246.)
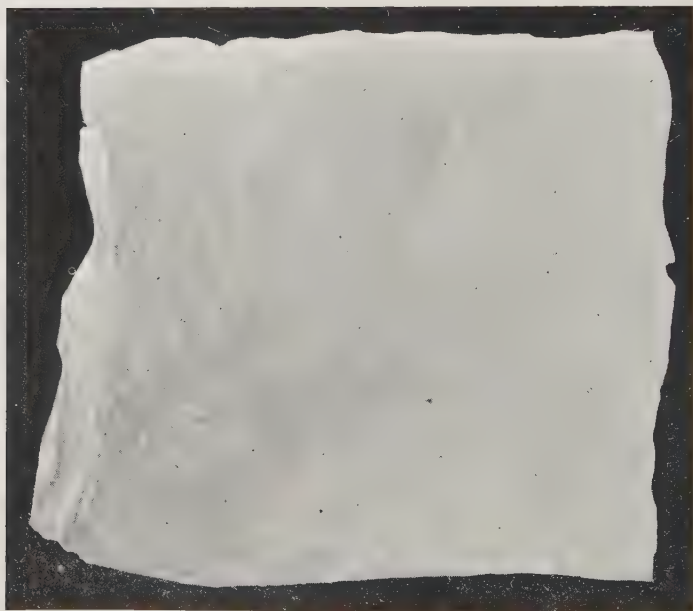
Fig. 246.—Slab of clay slate, Waterford, Vermont, showing the character of the cleavage surface. Photo. by C. H. Richardson.

(2) THE MEMPHREMAGOG SLATES.—This belt appears very narrow in Barnard in Windsor County, and widens to the northward to about 7 miles. It extends northward to Lake Memphremagog a distance of nearly 100 miles. In the more northern sections there are three distinct belts of slate with intervening limestone. The strike varies from north 10 de-

grees east to north 45 degrees east. Its dip is at a high angle to the west. It flanks the eastern edge of the Green Mountain range and is Ordovician in age. This slate has been quarried in Coventry in Orleans County, and in Montpelier and North-field in Washington County.

Montpelier.—The old Sabin quarries are located about one-half
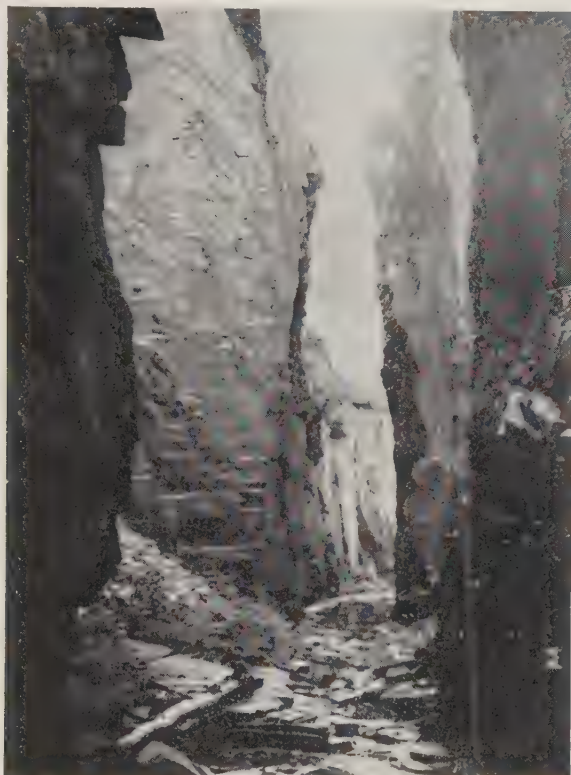
Fig. 247.—Interior of Sabin slate quarry, Montpelier, Vermont, showing cleavage and system of jointing. Photo. by C. H. Richardson.

mile east of the city of Montpelier. They were operated by means of three wide openings at intervals across the strike and communicating with each other by a ten-foot open cut, which also served as a drain. The strike of both bedding and cleavage varies from north 15 degrees east to north 20 degrees east and the dip from 70 degrees to 75 degrees west.

A large percentage of waste resulted from the manner in

which the quarries were opened. Secondary quartz veins also
increased the amount of waste. These facts are said to ex-
plain why the quarries are now idle. (See Fig. 247.)

Northfield. The quarries owned and operated by the Vermont
Black Slate Company are located about 10 miles south 10
degrees west from Montpelier and 2 miles south of Northfield.
The strike of the bedding varies from north 10 degrees east
to north 15 degrees east. The strike of the cleavage prac-
tically coincides with that of bedding but dips 15 degrees west.
The low easterly dipping planes as shown in Fig. 249, some-
what resemble a secondary cleavage, while the steep westerly
ones have the characteristics of bedding. The total width of
the slate at South Northfield exceeds 2,000 feet.

At the quarries of the Vermont Black Slate Company there
are no ribbons in the bedding and no horizontal joints in the

Fig. 248.—Slab of clay slate, Northfield, Vermont, showing perfect
cleavage. Photo. by C. H. Richardson.

cleavage. Therefore, channelling in a horizontal direction be-
comes necessary. On account of these factors it is easier to
obtain large slabs for mill stock than small ones for roofing
slates.

The slate is of dark gray color and fine texture. Its cleavage
surface is smooth and lustrous. It contains minute crystals
of pyrite with their longer axis pointing in the direction of the
grain. It also contains some non-metallic lenses. It is slightly
graphitic and magnetitic. (See Figs. 248 and 249.)

(3) The Cambro-Ordovician Belt.—This is by far the most important slate bearing district in the state. It furnishes the well known green and purple slates of large commercial significance. It lies between the Taconic range and Lake Champlain, and extends from the town of Sudbury in Rutland County, southward to Rupert in Bennington County, a dis-

Fig. 249.—Sabin slate quarry, Northfield, Vermont, showing the difference between the cleavage and bedding planes. Photo. by C. H. Richardson.

tance of 26 miles. This belt also passes to the southwest into Washington County, N. Y., where it has thus far proved of less economic importance.

Geological Relations.—According to T. N. Dale the Ordovician (Berkshire) schist of the Taconic range is bordered on the west, except for about 6 miles in Pawlet and Rupert, by a belt of Lower Cambrian rocks estimated at 1,400 feet in thickness.

These terranes include about 240 feet of greenish and purplish roofing slates. The boundary between the Ordovician and the Lower Cambrian rocks represents both an unconformity and a folded overlap. In Pawlet and Rupert the schists of the

Fig. 250.—Rising and Nelson slate quarry, Pawlet, Vermont, showing syncline in the seagreen slate. Depth 100 ft. By courtesy of the U. S. Geological Survey.

Taconic range merge at the west through decrease in metamorphism into an irregular area of shales and grits of Hudson River age. These terranes are 1,200 feet in thickness and include about 50 feet of commercial reddish and greenish slate. This formation has long been quarried in Granville and Hamp-

ton, N. Y., as described on page 277. In some instances the Lower Cambrian slate protrudes through the Ordovician areas while in others lenticular remnants of the Ordovician slate overlie the Lower Cambrian slate. (See Fig. 250.)

Color.—The Lower Cambrian slates of western Vermont are greenish gray, purplish and variegated. These colors occur in alternations. In the main the horizon seems to consist of greenish and purplish slates varying in thickness from 100 to 200 feet with the greenish shades predominating. The variegated or mottled overlying slate varies from 40 to 50 feet in thickness. On the west side of Lake Bomoseen nearly 100 feet of purple slate is exposed. The shade of green is not constant even in the same quarry, some being more greenish,
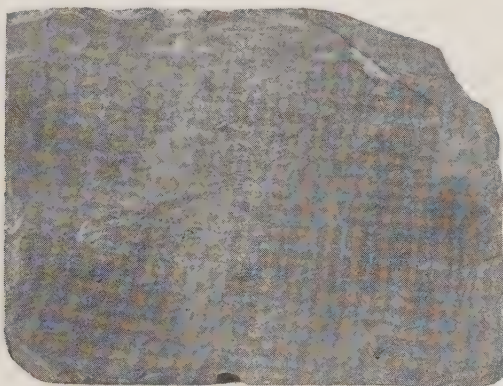
Fig. 251.—Slab of purplish black slate, Castleton, Vermont, showing perfect cleavage. Photo. by C. H. Richardson.

others more grayish. There is also a difference in the amount of discoloration produced by weathering in beds in the same locality. Some quarries produce only the so-called unfading green and others only the sea green. These differences appear not to belong to strata of different ages, but to occur at different points in strata of the same age. (See Fig. 251.)

Lower Cambrian.—The Lower Cambrian rocks consist of graywackes, roofing slates with beds of a calcareous quartzite and a limestone breccia, a sandstone with black shaly patches, black shale and slate, ferruginous quartzite and sandstone.

Ordovician.—The Ordovician rocks consist of shales, slates, grits and small quartzite beds.

Characteristics of Western Vermont Slates.

Sea Green Slate.—This slate varies from a light gray to a

greenish gray in color. In some beds it is crossed by ribbons of a dark gray color. The texture is fine, the cleavage surface smooth with a somewhat waxy luster. The sawn edge shows a little pyrite. It is feebly magnetitic and effervesces slightly with cold dilute HCl. It is sonorous and very fissile. On long exposure it changes to a brownish gray color. As the beds do not discolor uniformly a roof covered with sea green slate from different beds will present a mottled appearance. The discoloration is due to oxidation of the iron content of the calcite rhombs to limonite.

Unfading Green Slate.—This slate is greenish gray in color, with fine texture and a roughish, lusterless cleavage surface. It is magnetitic, but does not effervesce with cold dilute HCl. It is sonorous. This slate after several years of exposure to the corrosive agents of the atmosphere evinces no perceptible change unless placed beside a perfectly fresh slate and then the difference is slight. Acording to W. F. Hillebrand the permanency of color is due to the practical absence of rhombs and plates of carbonate.

Purple Slate.—This slate is a dark purplish brown. It occurs interbedded with the sea green and unfading green slates. Its texture is fine and cleavage surface smooth. It is sonorous. The carbonates occur in less abundance in this slate than in the sea green slate but it bears bright red dots of hematite ranging in diameter from 0.001 to 0.003 mm.

Variegated Slate.—The variegated slate is of greenish gray and purplish colors mixed. It is of fine texture with smooth cleavage and sonorous. The variegated slate of the Eureka quarry does not effervesce with cold dilute HCl.

Red Slate.—This slate is of reddish brown color which becomes brighter upon exposure. Its texture is fine, and its cleavage surface varies from slightly roughish to speckled with minute protuberances. It is magnetitic, hematitic, argillaceous, sonorous and sometimes effervesces with cold dilute HCl. Its color is due to the abundance of hematite. (See Fig. 242.)

Dove Slate.—This slate is of light gray color, fine texture and smooth cleavage surface. It contains a large amount of muscovite (sericite) and is sonorous.

Mill-Stock Slate.—In the northern and western part of the green slate area those beds which have a less perfect cleavage are used as mill stock. They are purple or green in color. The purple is often paler than the purple roofing slate, and also spotted with green. The green mill stock is sometimes brighter than the unfading green roofing slate.

Slate-Pencil Slate.—In the unfading green slate areas a little to the east of Lake Bomoseen there occurs a greenish slate that has been quarried and made into slate pencils.

In Europe slate pencils are manufactured by utilizing a secondary cleavage which breaks the rock up into squarish sticks that are easily rounded. In Vermont tile-shaped blocks of slate are carved out first on one side, then on the other, by means of set gauges, and thus a whole series of semicylindrical pencils which readily break apart into roundish pencils is prepared at once.

(4) THE BENSON BELT.—This district is located in the town of Benson, Rutland County, near Lake Champlain. The district comprises an area of 10 or 12 square miles and is practically undeveloped. The entire slate belt is about 25 miles in length, with strike in a northeasterly direction. The quarrying of black roofing slates in the belt has been confined to the town of Benson. These quarries were in operation in 1895, but are now abandoned. This slate is of Ordovician age.

The slate is bluish black in color. It has a fine texture, a smooth lustrous cleavage surface, and a fair degree of fissility. It is graphitic, magnetitic, effervesces with cold dilute HCl and is sonorous. It is closely related in both composition and quality to the "soft vein" slates of Lehigh and Northampton Counties, Pennsylvania.

Virginia.—Commercial slates occur in Virginia in Amherst, Buckingham, Fauquier and Fluvanna Counties.

Snowden, Amherst County.—The Snowden slate deposit is situated on the southeast side of the axis of the Blue Ridge, north of the cut through which the James River flows. It is also about 18 miles northwest of Lynchburg. The general strike of the slate formation is north 65 degrees east. About 250 feet of slate is exposed on the property of the Virginia Slate Mining Company. The structure is that of a flat-topped anticline.

This slate is of dark gray color, minutely granular texture, smooth cleavage surface, and very little luster. It bears no visible graphite, pyrite or magnetite. It possesses an argillaceous odor and is said to be unfading. It does not effervesce with cold dilute HCl and is sonorous.

Arvonia, Buckingham County.—The quarries near Arvonia are situated on both sides of Hunts Creek and a little to the northeast of Arvonia. The "Gig quarry" of the J. R. Williams Slate Company measures 300 feet along the cleavage, 200 feet across it, and 125 feet in depth. The bedding planes coincide

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with the cleavage planes. The strike is north 37° east and the dip is 86° to the southeast.

The "Middle quarry," which is owned by the same company, measures 500 feet along the cleavage, 350 feet across it and in places 350 feet in depth. The bedding and cleavage strike is north 33° east and the dip is 85° to the southeast.

The slate of the Williams quarries is of very dark gray color with a slightly greenish hue. It has a minutely granular texture, is slightly roughish and quite lustrous. It bears a little graphite, magnetite and pyrite. It is sonorous but does not effervesce with cold dilute HCl.

The Fontaine quarry of A. L. Pitts measures 300 feet along the cleavage, 200 feet across it, and 100 feet in depth. The bedding and cleavage strike is north 31° east and the dip is 80° to the southeast.

This slate is of dark gray color with a greenish hue. It has a granular crystalline texture and is roughish, on its cleavage surface. It bears a little graphite, magnetite and pyrite and is sonorous. It does not effervesce with cold dilute HCl.

Warrenton, Fauquier County.—There are several slate prospects in the neighborhood of White Sulphur Springs. The cleavage strike varies from north 25° east and west. The dip is about 25° to the west.

The slate is of bluish black color with moderately fine texture and cleavage surface. It bears graphite and pyrite but no magnetite. It is argillaceous and sonorous but does not effervesce with cold dilute HCl.

Bremo, Fluvanna County.—The Bremo quarries are situated about 2 miles northwest of Bremo Bluffs. The strike varies from north 18° east to north 23° east and the dip is nearly vertical.

The slate is of dark gray color, with fine and lustrous cleavage surface. It is slightly graphitic and pyritic but not magnetitic. It is argillaceous, sonorous and very fissile. It does not effervesce with cold dilute HCl.

According to E. O. Ulrich the Virginia slates are of Upper Devonian age.

West Virginia.—The slate belt of West Virginia is situated near Martinsburg in Berkeley County. This formation is designated in the Harpers Ferry folio of the United States Geological Survey as Martinsburg shale. The shale is estimated at from 700 to 1,000 feet in thickness and is of Ordovician age.

The old quarries of the Shenandoah Slate Company are

situated about 3 miles to the northeast of Martinsburg. The quarry is 100 feet in length, 70 feet in breadth, and 75 feet in depth. The strike of the bedding planes is north 25° east and the dip 15° south, and 65° east. The cleavage has the same strike as the bedding planes and dips at an angle of 75° in the same direction.

The slate is of black color with a slightly brownish hue. The texture is fine, the cleavage surface roughish and lusterless. The slate is carbonaceous, magnetitic, pyritic, sonorous and argillaceous but not graphitic. It effervesces with cold dilute HCl.

According to T. N. Dale the accessory mineral composition of this slate in descending order is calcite, muscovite, quartz, kaolin, pyrite, carbonaceous matter, chlorite and magnetite. It is a clay slate which is better adapted for mill stock than roofing purposes.

Some 2 miles to the south of Martinsburg there is another small quarry, 30 by 20 feet. The bedding strike is north 32° east and the dip 60-65° east. The cleavage strike is north 23° east and the dip 80° east.

About one mile southeast of Beddington there is a slate which bears fragments of feldspar and rutile needles. Several other small quarries are located in the Martinsburg district. They are all clay slates and none of them shows a complete seritization of the matrix. They are not sufficiently fissile, strong and elastic to successfully compete with mica slates for roofing purposes.

FOREIGN SLATES

Canada.—Slates of excellent quality, smooth, homogeneous, strong, and of green-red, purple and bluish black colors abound in the Province of Quebec. All of these varieties are imported and found in the principal slate markets of the United States.

Slate of good quality is also found at New Canaan, Nova Scotia.

England.—The Honister quarries, near Keswick, Cumberland, furnish a dark green, compact and fine grained slate in considerable quantities. The basement of the War Memorial Building in the City of York is an example of the value of this stone in structural work. The stone is of Ordovician age.

The Elterwater quarries, Ambleside, Westmoreland, offer a very fine grained slate of green color and Ordovician age. The War Memorial Building at Penrith presents an example of this slate.

France.—The slates of the Angers district are strong, tough and of bluish gray color. They have been used in many public buildings in France and exported somewhat from the port of Nantes. These slates are of Ordovician age. The slates in Morbihan are also of Ordovician age. They are strong, elastic and of pale gray color. The quarries are open cut on account of the frequent jointing in the slate which would make mining unsafe.

The Cambrian slates of the Ardennes district occupy a comparatively small area. They are micaceous, chloritic and contain abundant crystals of siderite. They frequently contain white spots which are richer in silica than the surrounding purple portions of the slate. In color the slates are purple, blue, grayish green and green. The green varieties contain crystals of magnetite. These small crystals are invisible upon the cleavage faces of the slate but can be observed upon the fractured ends of the slate blocks.

Wales.—According to J. Watson the Penrhyn quarries near Bangor in the northern part of Wales produce two types of fine roofing slates. The first is fine grained and of light blue color. The second is fine grained and of dark blue color. Both of these slates are of Cambrian age. These slates are very fissile and split readily into extremely thin sheets. The quarries are favorably situated both for working and shipment of the finished products. These materials have found their way to every quarter of the globe and doubtless the slates of northern Wales have been more extensively used for roofing purposes than any other slates of the world.

INDUSTRIAL FACTS ABOUT SLATE

Quarrying.—Before opening a slate quarry the commercial value and the grade of fissility of the slate should be determined by scientific and practical tests. The problems to be considered concern the thickness of the formation, the weathered top, the character of the jointing, the presence of faults, shear zone and dikes. The practical question of drainage, location of dumps, availability of fuel, and transportation facilities will also arise.

In quarrying slates ordinary blasting powder has long been used. The experienced workman will so manipulate his blast as to free large blocks from their bed without shattering the slate. Where slate quarries are traversed by veins of secondary quartz much good slate has been wasted by improper manipulation of blasts.

Channelling machines are now often used. The open cut method obtains in the United States, both in the opening of a quarry and in its subsequent development. The recent introduction of the method of tunnelling in the slate quarries of Angers, France, is a step in advance for three reasons. (1) It avoids the necessity of removing the overlying soil and weathered slate. (2) It protects the workmen during storms and in the winter. (3) It preserves the moisture in the exposed slate. Wherever the tunnelling method is adopted there should be a frequent inspection of the walls and roof to detect

Fig. 252.—Splitting slate, Pen Argyl, Pennsylvania. Photo. by J. N. Howell.

and mark all signs of rock movement in order that accidents may be averted.

Manufacture.—Roofing slates pass through three operations in the process of manufacture. These are blockmaking, splitting and dressing. In some instances they are also punched and counter-sunk. Formerly these operations were conducted by hand, but modern machinery is rapidly displacing hand work. (See Fig. 252.)

The slate is hoisted from the quarry in blocks which average about 6 feet by 3 feet by 1.5 feet. It is then conveyed to a cabin or shanty, where it is treated by a blockmaker, a splitter

and a dresser. The blockmaker, with a chisel, divides the original blocks obtained from the quarry into manageable slabs about 2 feet by 1.5 feet by 2 inches in thickness. In making the cut across the grain the process is termed sculping. A V-shaped notch is cut in one end of the block and trimmed out with a smooth gouge to a groove extending across the end of the block. The splitting chisel is held with edge ver-
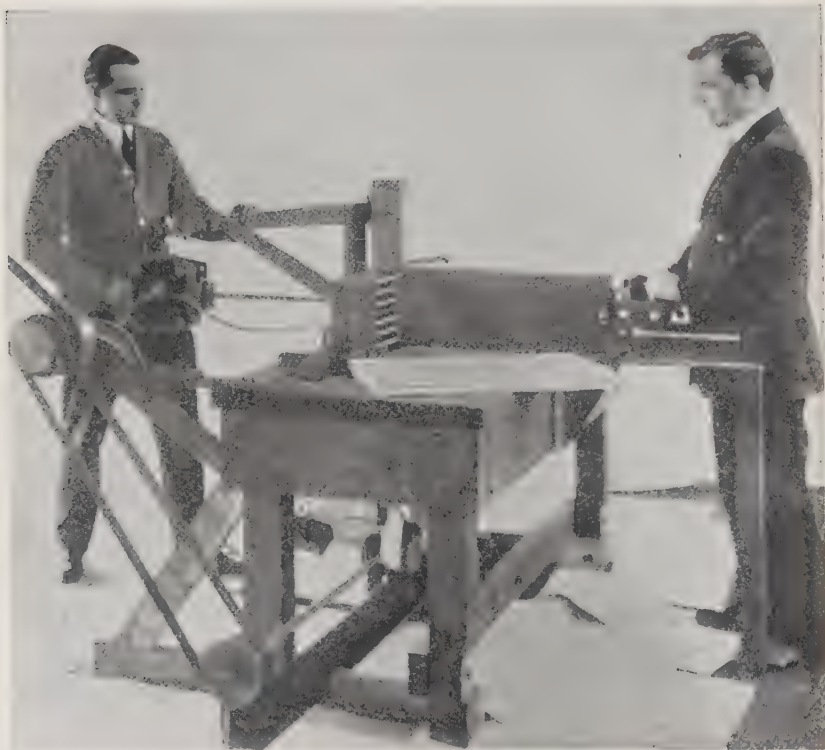
Fig. 253.—Slate splitting machine in operation. By courtesy of the U. S. Geological Survey.

tical to this notch and then struck with a hammer. The slab then passes to the splitter, whose splitting chisel is about 12 inches long and with an edge from 2 to 3 inches broad. This chisel is driven with a maul into the slate along the cleavage planes, and then worked backward and forward until the slate splits. The splitting is continued until the slabs are reduced to a thickness of one-eighth to one-fourth of an inch. The slate now passes to the dresser or trimmer, who formerly

trimmed all slates with a knife. Hand and foot power dressing machines are now largely used. The design is a long knife set vertically and hinged at one end. The other end of the knife is alternately raised or lowered by hand or by a treadle. (See Fig. 253.)

Splitting is still done by hand labor, as mechanical splitters have rarely given good satisfaction. The blocks are often given at least one sawed edge before they are passed on to the splitter. This is done on a sawing table with a vertical saw such as is used in the preparation of mill stock.

Measurement.—Two different units of measurement appear in the slate trade. The square is used in all American markets and the mille in all French and English markets. The square is the number of slates of a given size required to cover 100 square feet of roofing, with a given lap.

E. C. Eckel in his "Building Stone and Clays" gives the following formula: Let b equal the breadth of slates, d equal the length of slates and l equal lap. Then the number of slates to the square will equal 14,400 divided by one-half bd-bl, or 28,800 divided by bd-bl. This formula can be used for computing the number of slates to the square for any given size and lap. b, d and l are in inches.

The mille is 1200 slates of any given size. In Europe slates are shipped at the purchaser's risk and 60 slates are added to cover breakage. The actual mille therefore becomes 1,260 slates.

If, for a lap of 3 inches, slates are cut

    3 x 7 inches one square will require 2,400 slates
    4 x 7 inches one square will require 1,800 slates
    4 x 9 inches one square will require 1,200 slates
    8 x 9 inches one square will require   600 slates
    14 x 24 inches one square will require   98 slates

Uses.—The wide range of color, texture and composition in slates renders them capable of wide industrial application. Nearly all slates possess one or more excellent features, few possess many such features and none possess them all. The soft-vein slate of Pennsylvania is well suited for blackboards, slates, slate pencils, billiard tables, mantels and urinals. The red roofing slates of New York and Vermont, because they increase in brightness of color on prolonged exposure, make excellent roofing material. The fadeless bright green slates associated with the red slates are perhaps equally desirable

for roofing purposes. The black unfading slates of the Peach Bottom district of Maryland and Pennsylvania, of Arvonia, Penlan and Esmont in Virginia, and of Monson and Brownville in Maine, are all good roofing slates. The almost unfading green slates of Vermont will always be in demand. The sea green slates of Vermont and the black slates of Lehigh and Northumberland Counties, Pennsylvania, carry a content of ferrous carbonate. Some architects are reported as preferring such fading slates for aesthetic reasons.

Slates are used also for underpinnings, floor tiles, risers and treads of stairways and for flagging purposes. Slate is sometimes marbleized for mantels and fireplaces. Any kind of stone may be imitated but the verd antique marble, of Vermont and the variegated marble of Tennessee are those most frequently seen imitated.

Mill stock is used for electrical purposes. This use requires a minimum amount of magnetite.

Slates may be used to good advantage for inexpensive tablets and gravestones. There are many places where thick slate slabs with their high transverse strength may be used to advantage instead of concrete beams. Slate has also been substituted as veneers for laths.

Slate Waste.—The percentage of waste in slate quarrying and manufacture has been estimated by N. Watrin for the Ardennes region as varying from 70 to 75 per cent of the total weight. From 20 to 25 per cent is lost in the quarrying and about 50 per cent in splitting the slabs.

G. P. Merrill has estimated the total waste in the Peach Bottom district as 88 per cent. The waste in all quarries is large and the substitution, wherever practicable, of mechanical cutting machinery for blasting is probably the most available method for effecting this reduction.

In several localities slate waste has been utilized in the betterment of roads. The growing use in roofing of granulated slates consumes slate with imperfect cleavage. These slates near the ridge are one-fourth inch in thickness and at the cornice are one and one-half inches in thickness. The Inlaid-Slate Company of Bangor, Pa., utilizes slate 3 inches square embedded in a mixture of asphalt with a high melting point and a backing of roofing felt for covering flat roofs. Powdered slate is used as a filler for oilcloth and other fabrics. The waste of the bright red slate quarries of Granville, New York, is used for roofing and bridge paint. It is mixed with oil and white lead.

In Norway waste slate is powdered and mixed with either solid or liquid casein, according to the nature of the slate. The casein may be pure or mixed with lime, soda, resins or acids, according to the character of the product desired. Coloring matter is often introduced to produce different tints. The material when plastic is placed in molds and subjected to pressure. The product is then air dried. The resultant product has many properties identical with slate but is stronger and tougher.

The compressed slate can be sawed, planed and polished. All manner of fancy designs can be imprinted on the plastic slate, which may be manufactured into blocks of uniform size. The material is designed for covering walls, either internally or externally, in the place of ordinary wall paper or plaster. It also enhances the picturesqueness of slate roofs. Embossed mantlepieces are also possible.

Comparative Tests.—The transverse strength of slates is of considerable importance and should always be known before selecting a given slate for building purposes. In the best slates the modulus of rupture expressed in pounds per square inch should range from 7,000 to 10,000. M. Merriman has devised a method of determining this strength and gives the results as follows:

	Lbs. Per Sq. In.
Green, Vermont	6,410
Albion quarry, Pen Argyl, Pa.	7,150
Green, Rising and Nelson, Vt	7,250
Green, Granville, N. Y	8,050
Dark gray, Arvonia, Va	9,040
Gray, Monson, Me.	9,130
Red, Granville, N. Y	9,220
Dark gray, Chapman, Pa	9,460
Dark gray, Bangor, Pa	9,810
Dark gray, Arvonia, Va	9,850
Gray, Brownville, Me	9,880
Peach Bottom district, Penn.-Md	11,260

Chemical Analyses.—A few analyses of slates are appended here as a matter of reference. In order to give a correct idea of the composition of slates these analyses should not be partial but complete. The strongest and best slates are those with the highest percentage of silicates of iron and alumina, but these slates need not necessarily be the lowest in their carbonates of lime and magnesia. Chemical analyses should

always be supplemented with a microscopic analysis, tests for
transverse strength, elasticity, porosity, and corrosibility.

1. Sample of slate from the Old Franklin quarry, Slating-
ton, Pa. The analysis was made by W. F. Hillebrand.

Silica, SiO_2	56.38%
Alumina, Al_2O_3	15.27
Ferric oxide, Fe_2O_3, approximate	1.67
Ferrous oxide, FeO	3.23
Magnesia, MgO	2.84
Lime, CaO	4.23
Soda, Na_2O	1.30
Potassa, K_2O	3.51
Water below 110 degrees F., H_2O	.77
Water above 110 degrees F., H_2O	4.09
Titanium dioxide, TiO_2	.78
Zirconium dioxide, ZrO_2	Trace
Carbon dioxide, CO_2	3.67
Phosphorous oxide, P_2O_5	.17
Chromium oxide, Cr_2O_3	Trace
Manganous oxide, MnO	.09
Baryta, BaO	.08
Strontia, SrO	Trace
Lithia, Li_2O	Trace
Pyrite, FeS_2 including 0.92 sulphur	1.72
Carbon or carbonaceous matter, C	.59

100.39

2. Samples of roofing slate from Maryville, Tenn. Analysis
made by Gilbert McCulloch of the University of Tennessee.

Silica, SiO_2	58.45
Alumina, Al_2O_3	21.88
Iron oxide, Fe_2O_3	6.04
Lime, CaO	1.86
Magnesia, MgO	.46
Potassa, K_2O	1.60
Soda, Na_2O	2.34
Sulphur trioxide, SO_3	.65
Water, H_2O	6.66

99.94

3. Sample of purple slate from Utah. Analysis by W. T.
Schaller in the laboratory of the United States Geological
Survey.

Silica, SiO_2 ....54.05
Alumina, Al_2O_3 ....20.95
Iron oxides, FeO, Fe_2O_3 .... .28
Lime, CaO .... .22
Magnesia, MgO 9.12
Carbon dioxide, CO_2 and water, H_2O 3.90
—————
88.52

4. Sample of sea green slate from West Pawlet, Vermont. Analysis was made by W. F. Hillebrand.

Silica, SiO_2 ....62.76
Rutile, titanium dioxide, TiO_2 .... .71
Alumina, Al_2O_3 ....19.12
Ferric oxides, Fe_2O_3 .... .81
Ferrous oxide, FeO 4.71
Manganous oxide, MnO .... .10
Nickelous and cobaltous oxide, NiO, CoO........Trace
Lime, CaO .... .63
Baryta, BaO .... .04
Magnesia, MgO 2.38
Potassa, K_2O 3.52
Soda, Na_2O 1.39
Lithia, Li_2O ....Strong
Water below 110 degrees F., H_2O .... .23
Water above 110 degrees F., H_2O............ 2.98
Phosphorous oxide, P_2O_5 .... .07
Carbon dioxide, CO_2 .... .10
Pyrite, FeS_2 .... .22
Sulphur trioxide, SO_3 ....Trace
Carbon, C ....None
—————
100.07

5. Sample of red slate from Hampton, New York. Analysis made by W. F. Hillebrand.

Silica, SiO_2 ....67.61
Titanium dioxide, TiO_2 .... .56
Alumina, Al_2O_3 ....13.20
Ferric oxide, Fe_2O_3 .... 5.36
Ferrous oxide, FeO 1.20
Manganous oxide, MnO .... .10
Nickelous oxide, NiO............................Trace
Cobaltous oxide, CoO ....Trace
Lime, CaO .... .11
Baryta, BaO .... .04
Magnesia, MgO 3.20

Potassa, K_2O 4.45
Soda, Na_2O .... .67
Lithia, Li_2O .... Trace
Water below 110 degrees F., H_2O .... .45
Water above 110 degrees F., H_2O 2.97
Phosphorous oxide, P_2O_5 .... .05
Carbon dioxide, CO_2 .... None
Pyrite, FeS_2 .... .03
Carbon, C .... None

      100.00

Total sulphur, S .... .016

6. Sample of black roofing slate from Benson, Vermont. Analysis was made by W. F. Hillebrand.

Silica, SiO_2 .... 59.70
Titanium dioxide, rutile, TiO_2 .... .79
Alumina, Al_2O_3 .... 16.98
Ferric oxide, Fe_2O_3 .... .52
Ferrous oxide, FeO 4.88
Manganous oxide, MnO .... .16
Nickelous oxide, NiO .... Trace
Cobaltous oxide, CoO .... Trace
Lime, CaO 1.27
Baryta, BaO .... .08
Magnesia, MgO 3.23
Potassa, K_2O 3.77
Soda, Na_2O 1.35
Lithia Li_2O .... Strong trace
Water below 110 degrees F., H_2O .... .30
Water above 110 degrees F., H_2O 3.82
Phosphorous oxide, P_2O_5 .... .16
Carbon dioxide, CO_2 .... 1.40
Pyrite, FeS_2 .... 1.18
Sulphur trioxide, SO_3 .... Trace
Carbon, C .... .46

      100.05

Total sulphur, S .... .63

REFERENCES

Aubury, L. E. The Structural and Industrial Materials of California, 1906.

Barnum, G. Slate Mining versus Quarrying; Stone, Vol. 28, pp. 219-227, 1907.

Bayley, W. S. Slate from Monson, Piscataquis County, Maine; U. S. Geol. Survey Bull. 150, 1898.

Brunner, H. Valuation of Roofing Slates; Soc. Chem. Ind. Jour., Vol. 9, p. 393, 1890.

Chamberlin, T. C. and R. D. Salisbury. Geology, Vol. 1, Geologic Processes and Their Results; New York, 1904.

Coons, A. T. Slate; U. S. Geol. Survey, Mineral Resources, 1904-1910.

Dale, T. N. The Slate Belt of Eastern New York and Western Vermont; U. S. Geol. Survey, Nineteenth Annual Report, Part 3, pps. 153-307, 1899.

Dale, T. N. Slate Deposits and Slate Industry of the United States; U. S. Geol. Survey, Bull. 275, 1906.

Dale, T. N. and Others. Slate in the United States; U. S. Geol. Survey Bull., 586, 1914.

Davies, D. C. A Treatise on Slate and Slate Quarrying, Scientific, Practical and Commercial; 3d. Edition, London, 1887.

Eckel, E. C. Building Stones and Clays; John Wiley and Sons, 1912.

Eckel, E. C. The Slate Deposits of California and Utah; U. S. Geol. Survey Bull, 225, 1903.

Ferguson, E. G. W. Peach Bottom Slate Deposits, Pennsylvania; Min. World, Vol. 33, pp. 183-184, 1910.

Fox, H. The Variegated Slates of North Cornwall, England, 1906.

Hitchcock, C. H. Roofing Slates in Maine; Preliminary Report, Nat. Hist. and Geol. of Maine, pp. 316-319, 1861.

Howe, J. A. The Geology of Building Stones; London, 1910.

Hull, E. A. A Treatise on Building and Ornamental Stones, London, 1872.

Leighton, H. Slate (Industry) in New York in 1909; N. Y. State Museum Bull. 142, 1910.

Merrill, G. P. Stones for Building and Decoration; New York, 1908.

Nevins, J. N. Roofing Slate Quarries of Washington County, N. Y.; New York State Museum 53d. Ann. Rept. for 1899, Albany, 1912.

Perkins, G. H. Report of the State Geologist on the Mineral Industries of Vermont, 1900.

Purdue, A. H. The Slates of Arkansas ; Geol. Survey Ark., 1909.

Richardson, C. H. The Terranes of Orange County, Vermont; Ann, Rept. State Geologist, 1902.

Ries, H. Building Stones and Clay Products ; A. Handbook for Architects. New York, 1912.

Shaler, N. S. Slates, Description of Quarries and Quarry Regions ; 10th. Census U. S. Vol. 10, Part 2, 1880.

Smith, T. C. Slate Quarrying in Wales, 1860. Also two later Editions.

Watson, J. Building Stones ; Cambridge, 1911.

Watson, T. L. Slate in Virginia ; Virginia Geol. Survey Bull. 6, 1911.

Whedon, M. D. New York-Vermont Slate Belt ; Stone, Vol. 28, pp. 214-218, New York, 1907.

CHAPTER VII

SERPENTINE AND STEATITE

In the minds of many scientists the correct position of this chapter would fall at the close of the discussion of the building stones of igneous origin. The author of this work has chosen to place the discussion of serpentine and steatite at the close of the sedimentaries for two reasons: (1) Strictly speaking these two rocks are not directly igneous in origin. (2) They are of minor commercial significance as building materials.

These two minerals or rock masses have many points in common, although their uses are widely different. In composition they are hydrous silicates of magnesium. In origin they are alteration products of igneous rocks or minerals. Their similarities will be more fully brought out under the respective captions of serpentine and steatite.

SERPENTINE

Serpentine, Ophicalcite and Ophimagnesite.—The name serpentine is derived from the Latin word serpens, a serpent, in allusion to the snake-green color of the mineral or mottled appearance of the rock masses. It is applied not only to the mineral itself but also to the rock masses consisting essentially of the mineral serpentine.

Serpentine is a hydrous silicate of magnesium with formula $3MgO, 2SiO_2, 2H_2O$. If pure its percentage composition would be Silica 44.1 per cent. Magnesia 43.0 per cent. Water 12.9 per cent. Precious serpentine has a rich oil-green color, of pale or dark shades, and translucent even in slabs of considerable thickness. The common serpentine usually possesses the darker shades of color and is subtranslucent. As a rock mass it occurs frequently mixed with dolomite, magnesite and calcite. It is sometimes mottled with red and then it presents the appearance of a red porphyry.

Ophicalcite is the name applied to the spotted green and white varieties often appearing as crystalline marbles. It consists of a mixture of serpentine with calcite or dolomite, usually of sedimentary origin. Ophimagnesite is a name used for the first time by E. C. Eckel in his "Building Stones and

Clays" for a rock containing crystalline magnesite with disseminated serpentine. The term verd antique is not applied to the marble of any particular locality, but to all marbles containing disseminated seams, streaks, or masses of the mineral serpentine.

Origin.—Serpentine seldom if ever occurs as an original deposit. It usually is derived from the ultra-basic rocks rich in olivine, like peridotite. The products of the alterations of olivine, are serpentine, magnesite and sometimes magnetite. The pyroxene diopside may be metamorphosed into serpentine, calcite and quartz. In fact, serpentine may be derived from any silicate rich in magnesia, such as olivine, pyroxene, amphibole, garnet and chondrodite.

In the case of the ophicalcites and some serpentine deposits they appear to have been derived from an impure limestone rich in silica which was metamorphosed into a siliceous marble. The impurities present in the original sedimentary, with possibly some additional matter from other sources, gave rise to crystals of pyroxene, amphibole and other silicates. These silicates rich in magnesia were subsequently altered to serpentine.

Characteristics.—Serpentine is susceptible of a most beautiful polish when it does not contain disseminated magnetite, chromite and pyrite. The presence of these secondary minerals leads in time to a discoloration due to the oxidation and hydration of the iron content. The veins of talc, dolomite and magnesite with which serpentine is often traversed mark lines of weakness in the stone, for each represents a filled fracture. It is therefore impossible to obtain large blocks that will withstand high pressure. Most serpentine quarries are badly jointed and only small blocks can be obtained. The stone furthermore does not weather uniformly and is in general unsuited for exterior work. Some of the structures erected with serpentine from Pennsylvania evidence this variation.

AMERICAN SERPENTINES

California.—Serpentine forms extensive rock masses in the Coast Mountains of California. It occurs also in numerous small areas in the Sierras. Amador, Los Angeles and San Bernadino Counties have been the chief producers. The colors shade from a yellowish green to a very dark olive green. In most of the quarries it lacks a sufficient brightness of color to render it a desirable ornamental stone. According to L. E.

Aubury the quarries in San Bernadino County furnish as handsome stone as any in the United States. (See Fig. 254; also Fig. 136.)

Connecticut.—According to C. U. Shepard two quarries in this state were opened in the early part of the nineteenth century and subsequently abandoned. The working of the quarries was attended with heavy expense owing to the difficulty of obtaining blocks that were perfectly sound, of large dimensions, and to the labor required in sawing and polishing the marble. The Milford quarries can furnish handsome verd antique marble, while the New Haven quarries can produce a dove colored marble clouded with greenish yellow serpentine.

Georgia.—A massive verd antique marble is quarried in this
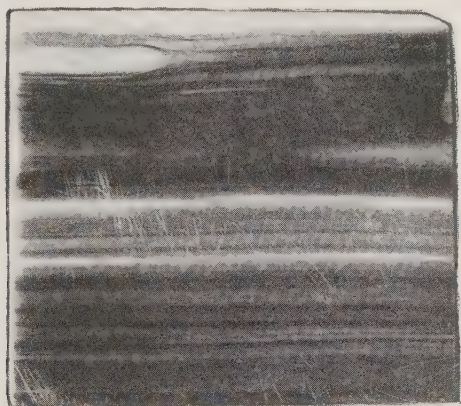
Fig. 254.—Polished slab of serpentine, Los Angeles County, California. Photo. by C. H. Richardson.

state near Holly Springs, Cherokee County. It is beautifully veined and well adapted to interior work.

Maine.—The best known serpentine quarries in Maine are situated on the northern end of Deer Isle, in Penobscot Bay. They are in close proximity to a good shipping wharf and larger blocks of serpentine can here be obtained than in most other quarries. The stone is of a dark green color, sometimes nearly black and somewhat somber. It is often veined with amianthus and diallage.

Maryland.—Near Broad Creek in Harford County there are two beds of serpentine which have been quarried from time to time for decorative material. The upper bed is about 500 feet in thickness and of green color. The lower bed shades in color

20

from a pale leek green to a deep blackish green. It is somewhat translucent, tough and harder than common marble.

Massachusetts.—There are many occurrences of serpentine in the Hoosic Mountains. W. O. Crosby has suggested that the quantity is adequate for the entire world, yet the quarries have never been extensively operated. Precious serpentine can be obtained in Middlefield and Pelham. Common serpentine for ornamental architecture occurs in the towns of Blanford, Middlefield, Newbury, Lynnfield and Zoar.

New Jersey.—Serpentine deposits occur in this state in the vicinity of Phillipsburg. They have been quarried to some extent for decorative interior work. The polished slabs are of exceptional beauty but blocks of only small dimensions appear to have been obtained.

New York.—Serpentine occurs on the west side of Lake Champlain in the vicinity of Moriah and Port Henry in numerous outcrops from which sound blocks of considerable size can be obtained. Too much resistance to compression must not be expected of these blocks. It receives a good polish and is better suited for decorative work than structural. This serpentine marble consists mainly of serpentine, dolomite, calcite and phlogopite.

North Carolina.—According to G. P. Merrill massive varieties of serpentine occur in many localities within this state. Good serpentine can be obtained near Patterson, Caldwell County. It is of a dark greenish black color, traversed by fine veins of yellowish green and silky chrysotile. This stone is susceptible of a good polish. Dark green serpentine has also been seen by the author near Asheville in Buncombe County.

Pennsylvania.—The best known serpentine in Pennsylvania is quarried near Easton. The small blocks obtainable are susceptible of a fine polish. The decorative effect of this stone can be seen in the interior of the Episcopal Cathedral of St. John the Divine in New York City.

Serpentine deposits are also abundant in the southeastern part of the state. A belt of serpentine nine miles in length is known to occur in Chester County. Quarries have been worked near West Chester and the product used for building purposes. It can be seen in some of the buildings of the University of Pennsylvania, in some of the churches of Philadelphia, in the Academy of Sciences, Philadelphia, and in the Monroe Avenue M. E. Church in Rochester. The church in Rochester is trimmed with a Triassic brownstone.

Vermont.—The serpentine belt of Vermont extends in a

somewhat northeasterly direction across the entire state. The old quarries in Cavendish, which were opened about 1835 to obtain a structural stone of great beauty, were soon abandoned. Distance from the railroad together with the cost of quarrying, dressing and polishing the stone made it too expensive to compete successfully with the well known marbles of western Vermont. This stone is of varying shades of green and receives a fine polish.

The best known American serpentine and in the author's

Fig. 255.—New quarry of verd antique marble, Roxbury, Vermont. Photo. by C. H. Richardson.

judgment the most beautiful is quarried at Roxbury in Washington County. The old quarries are situated within 100 rods of the Roxbury station on the Central Vermont railroad. Recent quarries have been opened up a little to the northeast of the old quarries. (See Figs. 255 and 256.)

The origin of this serpentine is through the alterations of a peridotite dike which was introduced into Cambrian sediments in pre-Ordovician time. About one mile east of the village of North Troy, Vermont, a dike of diabase cuts the steatite out-

Fig. 256.—Rough block of verd antique marble, Roxbury, Vermont, showing work of channelling machine.   Photo. by C. H. Richardson.

Fig. 257.—Diabase dike cutting steatite, North Troy, Vermont. Photo. by C. H. Richardson.

crop. The zone of metamorphism at the contact of the intrusives proves them not contemporaneous. This peridotite is exceedingly common in its more northerly extension into Canada where it cuts terranes considered to be Ordovician, but nowhere in Vermont does it cut strata of Ordovician age. Pebbles of serpentine have been found in the Irasburg conglomerate which forms the basal member of the Ordovician series in Vermont, therefore the peridotite belt in northern Vermont is of pre-Ordovician age. (See Fig. 257.)

The serpentine is somewhat fibrous and radial in texture with veinlets of dolomite and talc. The unpolished stone is of a dark purplish or greenish color traversed with many veins of white dolomite. The polished stone is of dark greenish black color, almost black, and decorated with veins of white dolomite and light green talc. These veins and veinlets are often sheared and faulted, which indicates that the stone has been subjected to powerful compression since its alteration to serpentine.

The belt of serpentine is known commercially as a verd antique marble. The high polish which it receives, together with the striking contrasts in shades and colors, and the faulted and sheared veins, renders this serpentine a very attractive ornamental stone for interior work. Too much must not be expected of it for constructional purposes.

In Orleans County the serpentine belt is practically continuous across the entire county. In the more northern portion two belts of serpentine appear which flank either side of the Missisquoi River. The largest single mass is on the eastern side of Belvidere Mountain in Lowell and Eden, where considerable quantities of chrysotile asbestos have been mined and marketed. (See Fig. 258.)

Washington.—Three varieties of serpentine marbles are quarried in Stevens County, Washington. They are commercially known as Athenian Green, Landscape Green and Royal Washington. These serpentines, like the eastern representatives, are best suited for decorative interior work.

FOREIGN SERPENTINES

Canada.—All of the varieties of serpentine obtained in northern Vermont may be duplicated in the Province of Quebec. The author has traversed this belt in its northeasterly extension into Canada for more than 100 miles, and its characteristics are essentially the same as those in Vermont.

England.—The serpentine deposits of Cornwall, England,

fall amongst the best known and most beautiful serpentine marbles of the world. They are prevailingly of a dark olive green color, veined, streaked and blotched with minerals of greenish white, chocolate brown and blood red hues.

Ireland.—The best known Irish serpentine is called Connemara marble. It is obtained in the County of Galway and has been imported as a decorative stone to some extent into the United States. The stone is of light to dark green color, mottled, streaked and variegated.

Fig. 258.—Massive serpentine traversed by veins of fibrous serpentine, chrysotile, northeast side of Belvidere Mountain, Lowell, Vermont. Photo. by C. H. Richardson.

Italy.—The ophicalcites of Italy are well known decorative stones. The Verde di Pegli is a breccia consisting of deep green fragments of serpentine cemented together with light green calcite. The Verde di Genova stone from the quarries at Pietra Lavezzara is also a breccia which consists of green, greenish black and brownish serpentine cemented with white or greenish white calcite. It has been quarried for many centuries and the product shipped largely to France. The Verde di Levante is a breccia containing fragments of serpentine of a violet or wine red color. The Verde di Prato is obtained from the serpentine quarries in Tuscany. It is of deep

green color and contains crystals or nodules of diallage. The network of fine lines or veinlets traversing this stone gives it the appearance of a breccia. The Nero Antica di Prato, which was extensively used for monuments by the ancients, is of dark green color.

INDUSTRIAL FACTS ABOUT SERPENTINE

Uses.—Serpentine has been used in many instances in the place of marble for structural purposes. The dressed stone does not weather uniformly for the white and yellowish veins lose their luster and crumble. The entire face of a building
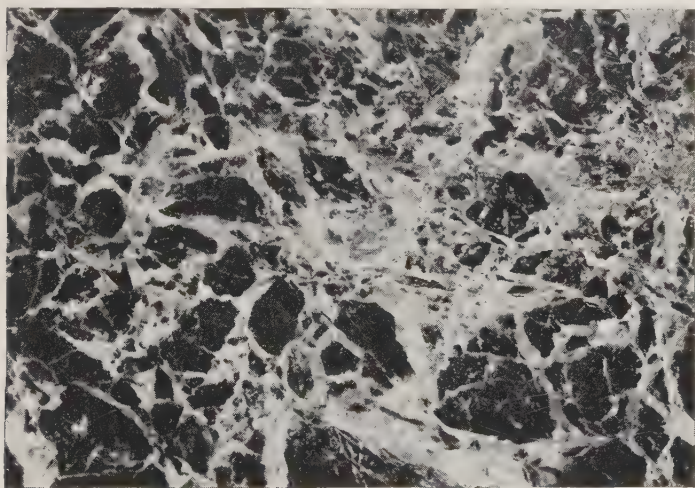
Fig. 259.—Polished slab of verd antique marble, Maryland. Photo. by C. H. Richardson.

may therefore become as unsightly as it once was beautiful. Its resistance to compression is too low for the more massive forms of architecture. It can be used to a good advantage in columns where only a moderate pressure is demanded. It has been used from time immemorial for monumental work in France and Italy. In later years it has been used somewhat for that purpose in America. It is sufficiently soft to be turned and polished on a lathe. Its beautiful colors when polished have made it a favorite with all civilized nations for decorative interior work and for small articles of ornamentation. (See Fig. 259.)

Ornamental fronts, pulpits, small shafts, pillars, pilasters,

vases, tazzas, choir steps, ambulatories and inlaid work utilize serpentine. The finely fibrous variety known as chrysotile is now being manufactured into fireproof lumber which can be planed, sawed and finished like ordinary lumber, and yet possesses all the advantages of fireproof material.

Compression Tests.—The resistance to compression of some well known serpentines is here given as a matter of reference.

	Lbs. Per Sq. In.
Gillespie County, Texas	8,950
Washington, Milan, dark	9,520
California, Auburn	11,590
Germany	11,950
Washington, Milan, light yellow	13,530
Washington, Chewelah	17,310
Washington, Valley, green	18,305
Washington, Valley, black	29,750

Chemical Analyses.—A few analyses are also appended as a matter of reference to show the general chemical composition of serpentines.

1. This sample is from Valley, Stevens County, Washington. The analysis was made by R. W. Thatcher.

Silica, SiO_2	38.47%
Alumina, Al_2O_3	0.16
Ferric oxide, Fe_2O_3	2.04
Ferrous oxide, FeO	Trace
Magnesia, MgO	39.86
Carbon dioxide, CO_2	4.84
Water, H_2O	14.63
	100.00

2. This sample is also from Valley, Washington, from the quarries of the United States Marble Company. The analysis was made by George Steiger. The large decrease in silica and increase in magnesia and water is notable.

Silica, SiO_2	13.08
Alumina, Al_2O_3	1.63
Ferric oxide, Fe_2O_3	1.25
Ferrous oxide, FeO	0.19
Lime, CaO	0.33
Magnesia, MgO	56.44
Carbon dioxide, CO_2	2.03
Water, H_2O	24.79
	99.74

3.   An old analysis of the verd antique marble of Roxbury, Vermont, gives the following:

Silica, SiO_2 ....42.60
Magnesia, MgO 35.50
Chromic and ferrous oxides, Cr_2O_3,
   FeO 8.30
Calcium carbonate, $CaCO_3$ 0.60
Water, H_2O 13.00

                                          ─────────
                                          100.00

4.   J. Watson in his book entitled "Building Stones" gives the following analysis of a sample of serpentine diabase from the Polyfant quarries near Launceston, Cornwall, England:

Silica, SiO_2 ....36.90
Alumina, Al_2O_3 ....11.80
Ferric oxide, Fe_2O_3 ....12.00
Ferrous oxide, FeO 3.56
Magnesia, MgO 15.03
Lime, CaO 2.80
Potash, K_2O 3.64
Soda, Na_2O ....Trace
Water, H_2O 13.16

                                          ─────────
                                          98.89

REFERENCES

No attempt is made to give a complete bibliography but simply to add a few references to some works bearing on the origin and occurrences of serpentine.

Aubury, L. E.   Structural and Industrial Materials of California; 1906.

Dresser, J. A.   Mineral Deposits of the Serpentine Belt of Southern Quebec; Ann, Rept. Canadian Geol. Survey, 1909.

Eckel, E. C.   Building Stones and Clays.   John Wiley and Sons, 1912.

Jacobs, E. E.   The Talc and Verd Antique Deposits of Vermont; Ann Rept. State Geol., 1916.

Jonas, A. J.   Serpentine in the Vicinity of Philadelphia; American Geologist, Vol. 36, pp. 296-304, 1905.

Hull, E.   Building and Ornamental Stones; Macmillan and Company, 1872.

Lyon, D. A.   Serpentine Marbles of Washington.   Mines and Minerals, Vol. 21, 1901.

Masters, W. F.   The Serpentine Belt of Lamoille and Orleans Counties, Vermont; Ann. Rept., State Geologist, 1904.

Mathews, E. B. Character and Distribution of Maryland Building Stones; 1898.

Merrill, G. P. Stones for Building and Decoration. John Wiley and Sons. Second Edition.

Ries, H. Building Stones and Clay Products; John Wiley and Son. 1912.

Richardson, C. H. Asbestos in Vermont; Ann. Rept. State Geologist, 1910.

Richardson, C. H. Asbestos Deposits of the New England States; Ann. Rept. Can. Inst. Min. Engineers, 1910.

Shedd, S. The Building and Ornamental Stones of Washington; Ann. Rept. Washington Geol. Sur., 1902. Vol. 2, pp. 1-163.

Wigglesworth, E. The Serpentine of Vermont. Proc. Boston Soc. Nat. Hist., 1915.

STEATITE

Steatite is the mineralogical name applied to massive talc. Soapstone is the commercial name applied to the same product. Steatite closely resembles serpentine in its chemical composition, mode of origin and in some of its physical properties. While serpentine is of varying shades of green, steatite is usually of dark bluish gray color. It may be grayish green or brownish gray in color. Its hardness varies from 1 to 2.5 and its specific gravity is 2.7.

Composition.—Steatite is a hydrous silicate of magnesium formula $H_2O, 3MgO, 4SiO_2$. If the rock mass contained no other minerals than talc its analysis would give 63.5 per cent silica, 31.7 per cent magnesia and 4.8 per cent water. This water of combination is liberated only at a red heat.

Talc or steatite is a very common mineral and in the massive form it constitutes extensive rock masses in many localities. It is often associated with serpentine, talcose schists, chlorite schists, siliceous magnesite, dolomite and gneiss. It frequently contains crystals of dolomite, breunnerite, chrysotile, actinolite, tourmaline, magnetite, pyrite and pyrrhotite.

Origin.—Talc, steatite or soapstone, has more than one mode of origin. Its most frequent derivation is by the alteration of amphiboles and pyroxenes. Carbonated waters acting upon magnesium silicates can develop steatite and magnesite. In the case of a calcium magnesium silicate, calcite is formed in addition to the steatite. Enstatite and tremolite are perhaps the two commonest minerals to undergo these changes.

The talc of northern New York, St. Lawrence County, is associated with crystalline limestones. C. H. Smyth considers that a siliceous limestone was first formed which became by metamorphism a tremolite-enstatite schist. This schist was in part subsequently altered to talc.

In the talc mines in Lewis County, about one mile from Natural Bridge, the talc is associated with crystalline limestones and serpentine. The origin here is from the alterations of the pyroxene enstatite. The author has here found many crystals with the structure of enstatite well preserved.

In the northern part of Vermont the talc deposits are derived from pyroxenite. In a cross section of the peridotite belt in North Troy, the central portion which originally consisted essentially of olivine has been altered to serpentine. The serpentine is flanked upon either side by a belt of steatite which has been derived from pyroxenite. The steatite is flanked upon either side by sericite schists. C. H. Hitchcock regards the soapstones of Francestown, New Hampshire, as derived by the alterations of wholly igneous rocks. These may have been pyroxenites. J. H. Pratt considers the talc deposits of North Carolina to have been derived from tremolite. They are associated with marble which is capped by quartzite. The mineral, pyrophyllite, which is a hydrous silicate of aluminum, occurs in the same region and may be mistaken for talc, which it closely resembles. It is used commercially to a smaller extent than talc.

Characteristics.—Steatite is sufficiently soft to be scratched with the thumb nail. It can easily be sawn into blocks and slabs with common saws. It has a decidedly soapy feel. It is insoluble in the mineral acids, which fact, together with its inferior hardness, renders the stone especially desirable for table tops and sinks in chemical and mineralogical laboratories. The pseudomorphous variety, rensselaerite, is however decomposed by concentrated H_2SO_4.

AMERICAN STEATITES

Arkansas.—There are large deposits of steatite near Benton, Saline County. The stone is of fine compact texture and brecciated.

California.—According to L. E. Aubury soapstone and talc occur in 23 counties in this state. The best known quarries are in Butte and Los Angeles Counties, where the stone has been worked for structural purposes.

Maine.—Beds of soapstone that have been worked to some extent occur on Orrs Island and at Jaquish and Harpswell in Cumberland County.

Maryland.—The soapstone beds of this state have been worked to a limited extent in Carroll and Montgomery Counties. The rock mass is badly jointed and only blocks of small dimensions can be obtained.

Massachusetts.—Soapstone quarries have been operated for many years in Lynnfield in Essex County. This stone is extremely soft when first quarried but hardens upon exposure to the atmosphere. This stone has found use in sills, risers, treads and stoves. The larger quarries of the state are situated at North Dana in Worcester County, and these have been extensively worked for more than half a century.

New Hampshire.—The extensive beds of soapstone in Francestown, Grafton County, were discovered in 1794 and opened in 1802. They have been in operation much of the time for more than a century. The stone is fairly uniform and blocks of good dimensions have been obtained. The soapstone is of uniform dark color. Steatite beds also occur in Haverill, Orford and Warren in the same county. Some quarries have been opened and worked intermittently. Other beds occur in Canterbury and Weare in Merrimack County, and in Richmond in Cheshire County.

New York.—The talc deposits of St. Lawrence and Lewis Counties are amongst the best known producers of this mineral in its fibrous form in the United States. The soapstone is fairly uniform, tough and refractory.

North Carolina.—There are many scattered occurrences of soapstone in the southwestern part of the state. The Nantehala stone from Cherokee County is a pure and nearly white compact talc which is generally regarded as equal to the best French chalk so largely used by tailors. The so-called soapstone of Deep River is in reality pyrophyllite. It is ground and bolted like the talc.

Pennsylvania.—Steatite has been quarried for many years along both banks of the Schuylkill River and used for sills, steps, furnaces, stoves and fireplaces. It has also been quarried on the west side of the Wissahickon River.

South Carolina.—Beds of soapstone are known to occur in at least ten counties in South Carolina, yet it has not been extensively quarried. The largest quarries have been opened in Anderson and Pickens Counties.

Texas.—The beds of soapstone in Texas appear to be inex-

haustible in quantity. A product of good quality is obtained from Llano County.

Vermont.—The peridotite belt that traverses nearly the entire length of the state to the east of the Green Mountain axis bears numerous outcrops of steatite, in scattered occurrences, that have resulted from the alteration of pyroxenite. Some of these beds or veins are of greenish white color and quite pure as in Moretown and Waterbury in Washington County, while others are of the common dark gray color, as

Fig. 260.—Talc mill, Waterbury, Vermont. The entrance to the mine is directly above the left-hand upper corner of the mill. Photo. by C. H. Richardson.

in the more northern portions of the state. The beds in the southeastern portion of the state as in Grafton are associated with gneiss and may have been derived from minerals of the amphibole family bearing calcium and magnesium. (See Fig. 260.)

Virginia.—Probably the best known steatite beds of Virginia are those of Alberene in Albemarle County. This stone is uniformly soft, of even, fine texture and rather light to dark color. Blocks of good dimensions are easily obtained which are sawed into slabs for table tops, sinks and stationary wash-

Fig. 94.—Quarry of the Alberene Stone Company, Schuyler, Nelson County, Virginia. By courtesy of the Alberene Stone Company.

tubs. This stone is occasionally traversed by narrow white veins. Samples of this stone immersed for 48 hours in nitric acid show a pitted surface due to a solution of calcium and iron bearing minerals. There are at least four distinct belts of soapstone in the state. Their general trend is to the northeast. Several quarries have been opened in these beds and the product is of good quality. (See Fig. 261.)

Fig. 262.—Alberene stone hoods, table tops, sinks and shelving, installed at the Bethlehem Steel Company's plant, South Bethlehem, Pennsylvania. By courtesy of the Alberene Stone Company.

INDUSTRIAL FACTS ABOUT STEATITE

Uses.—Steatite is suited in many ways to a wide variety of applications. It is one of the most indestructible of building stones although one of the most limited in its uses as such. To many architects and engineers it is too somber in color and too greasy in feel for structural purposes. In risers and treads it has often proved unsuitable. It wears away rapidly. When it contains masses of serpentine these, with their greater resistance to abrasion, stand up as knobs or unsightly protuberances upon the stone. (See Figs. 262, 263 and 264.)

It is most admirably adapted for table tops, sinks, vats, stationary washtubs, refrigerators, fireplaces, furnaces, stoves, mantels, fire brick, hearthstones, warmers, grills and griddles. The waste material when free from grit can be pulverized and used as a lubricant or a white earth. Large quantities are consumed annually in the manufacture of soap. It increases the weight of the soap but not its power of solution. It is used extensively as a filler in the manufacture of paper by the sul-

Fig. 263.—Alberene stone table tops, shelves and hoods, Melon Institute, University of Pittsburg, Pittsburg, Pennsylvania. By courtesy of the Alberene Stone Company.

phite process. Here also it needs to be free from grit. It is also used in the dressing of fine skins and leather. Shoe and glove dealers consume annually an appreciable quantity of this commodity. The base of many toilet powders is talc. This is often mixed with borax.

Crayons and pencils are manufactured from the creamy white varieties. French chalk is a pseudomorphous variety that is imported and used by tailors. The fine grained and compact varieties are manufactured into many small orna-

ments. Tips for gas burners reveal the ease with which the stone may be manufactured into small objects of considerable commercial value. Since it can be carved into fine sharp lines it has been somewhat a favorite for grotesque images. Talc has furthermore been used as the body of paint and in the manufacture of plaster.

Fig. 264.—Alberene stone hood, Melon Institute, Pittsburg, Pennsylvania. By courtesy of the Alberene Stone Company.

The largest part of the fibrous talc of the United States comes from St. Lawrence County, New York, and enters largely into the manufacture of paper and soap. Virginia takes the lead in the manufacture of articles of utility from soapstone, while North Carolina stands first in the production of pyrophyllite.

REFERENCES

A few references are here given to some of the more important papers dealing in part or entirely with talc and steatite.

Keith, A. Talc Deposits of North Carolina; Bull. 213, U. S. Geological Survey, 1903.

Eckel, E. C. Building Stones and Clays; J. Wiley and Sons, 1912.

Jacobs, E. C. Talc and the Talc Deposits of Vermont; Ann. Rept. State Geologist, 1914.

Merrill, G. P. Stones for Building and Decorating; Second Edition, J. Wiley and Son, New York.

Nevius, J. N. Fibrous Talc in St. Lawrence County, New York; Engineering and Mining Journal, Vol. 67, pp. 234, 235, 1899.

Nevius, J. N. The Talc Industry of St. Lawrence County, New York; 51st Ann. Rept. N. Y. State Museum, 1899.

Perkins, G. H. Soapstone in Vermont; Report Vermont State Geologist, 1900.

Richardson, C. H. Geology of Newport, Troy and Coventry, Vermont; Ann. Rept. State Geologist, 1908.

Smyth, C. H. Report of the Talc Industry of St. Lawrence County, N. Y.; 15th Ann. Rept. N. Y. State Geologist, Vol. 1, 1897.

Watson, T. L. Talc and Soapstone in Virginia; Mineral Resources of Virginia, Richmond, 1907.

CHAPTER VIII

CLAYS

Definition.—The term clay is one that scarcely admits of a concise definition. It is one of the many substances which result from the decomposition of different types of rock. It is generally fine grained, unconsolidated, and when wet it is more or less plastic. It loses the property of plasticity when strongly heated and becomes exceedingly hard. When wet, plastic clays may be molded into any desired shape, and this property of plasticity is required in the definition of commercial clays. Kaolinite is often referred to as the base of clays, but true kaolinite is not plastic.

Mineralogical Composition.—Kaolinite is a hydrous silicate of aluminum. Its formula is $2H_2O$, Al_2O_3, $2SiO_2$. It is often associated with its ferric equivalent, nontronite, whose formula is $2H_2O$, Fe_2O_3, $2SiO_2$. Free silica, either as quartz or opal, is present. Also many fragments of undecomposed minerals and the hydroxides of several metals. Kaolinite is a stable mineral but nontronite is decomposed by acid and alkaline solutions into ferric hydroxides which yield limonite as a final product. The mineral composition is as varied as the types of rock from which the clays are derived and the amount of alteration that the clays themselves have undergone. As the clay bed is hardened by pressure it passes into a shale. The fire clays of the coal measures of Pennsylvania and elsewhere are strictly speaking shales. By pressure sufficiently intense to produce fissility shales pass into slates.

Chemical Composition.—Silica and alumina are essential in all clays. The oxides of iron are almost invariably present. Lime, magnesia, various alkalies and sulphur are of frequent occurrence. Analyses of clays as cited later must vary widely on account of these differences in their mineral content and chemical composition.

Size of Grains.—The size of the individual particles varies from the finest of dust up to fragments one-thousandth of a millimeter in diameter. These finer products of rock decay should predominate over the grains of sand that are visible to the naked eye. The fineness of a clay may be roughly determined by thoroughly agitating a given weight of clay in a flat bottomed

flask. The coarse material settles quickly to the bottom of the flask, while the finest particles remain in suspension several hours.

Origin.—Clay is one of the results of the decomposition of aluminous minerals, especially the feldspars of granites, gneisses, porphyries and feldspathic schists. Vast beds of kaolin sometimes occur where these feldspathic rocks have decomposed on a large scale. The kaolinization of any highly feldspathic rock may yield a mass of nearly pure white kaolin. Quartz and scales of mica in small quantities interfere but little with the color of the resulting product. Kaolinite is the mineralogical name, but when the mass arrives at the dignity of a rock formation it is termed kaolin.

Kaolinite is commonly accepted as the chief residual product of feldspathic decay due to chemical and physical causes. Chemical agents dissolve out the soluble constituents of rocks. Organic acids set free by decomposing vegetable matter are solvents of rock constituents. The expansion and contraction due to changes in temperature are potent agents in rock disintegration. H. Rosler believes that kaolinite is produced only by pneumatolytic action—that is, by the combined influence of thermal waters and gaseous emanations. Clay deposits are the result of two sets of agencies. The one is chemical. The other is mechanical.

(1) *Residual Clays.* — These clays result from the kaolinization of highly feldspathic rocks with the product remaining in situ or in close proximity to the place of origin. They are derived from the decay of igneous rocks, the decay of shales and slates and the decay of argillaceous limestones.

(2) *Transported Clays.* — Such material is borne mostly from its place of origin by the agency of rivers. In certain instances it is transported by the agency of glaciers and in others by the winds. These may be subdivided into (a) marine clays that are still soft; shales and slates. These were all formed in salt water basins. (b) Stream clays that have been deposited along brooks and rivers. Such deposits are more or less sandy for they often represent deposits formed by streams during their periods of overflow. (c) Lake clays which were laid down on the areas bordering the Great Lakes during their earlier stages of existence. They have also been deposited in many small lakes and ponds in the area covered by the great ice mantle of the glacial epoch. (d) Glacial clays which have been formed in part by the scouring action of the glaciers, transported and deposited by them. (e)

Eolian clays which have been transported by the agency of the wind and the deposits influenced, somewhat in certain cases by temporary streams.

Residual Clays.—Such clays remain in or near the place where the original rock is disintegrated. Pegmatite veins are especially prone to yield kaolinite in their decomposition. Gneisses, feldspathic schists and even dolomites have produced them. Such clays retain in their lower portions many angular fragments of undecomposed minerals, while the number of such fragments will increase as the parent rock is approached. The depth which residual clays attain depends upon the amount of work done by both chemical and mechanical agents and the angle of slope upon which the clays rest. Valleys and flats are their especial home, where they sometimes assume great thickness.

Sedimentary Clays.—Sedimentary or transported clays are those that no longer rest upon the parent rocks from which they have been derived. They have been transported by various agencies to regions more or less remote from their place of derivation and deposited along river beds, in lakes or on the floor of the sea. They bear no genetic relation to the rocks beneath them. A series of beds of similar or of dissimilar character may appear within a given area. These may be overlain with sediments consisting essentially of sand or mixed sediments of sufficient depth to compress the clay beds into shales.

Glacial Clays.—Glacial clays, as the name implies, comprise the rock flour that has been deposited beneath or in front of glaciers. They owe their position to the transporting power of glaciers. They owe their origin to the engraving and grinding tools in the lower portion of the glacier. Their composition varies markedly from the other clays, for they were formed under conditions that protected them in some measure from the chemical agents of the atmosphere. They contain more soluble matter than the clay formed by normal weathering agencies, whether residual or transported. These differences will be conspicuous in the analyses. Glacial clays are of considerable importance but of somewhat limited distribution.

Eolian Clays.—Such clays are often called wind-borne clays because they are considered by many scientists to have been transported and deposited by winds. They are also called loess clays. In chemical composition they bear a close resemblance to glacial clays. They usually contain calcium carbonate in appreciable amounts. They are of limited extent and minor importance. The striking peculiarities of the loess clays are their light color, their extremely fine state of subdivision, the angularity of

their constituents, the absence of stratification in the beds, together with their coherence and porosity.

Origin.—F. Richthofen considers the loess of China as an eolian deposit. In Central Asia wind blown dust comes to rest wherever it is entangled and protected by the grasses of the steppes. Small temporary streams that result from showers aid in the accumulation of loess in valleys and other depressions.

The adobe deposits of the Great Basin contain the finer products of subaerial erosion of mountain slopes, and may even be commingled with dust of volcanic origin. This material was deposited in playa lakes whose beds are dry during a great part of the year. The loess of the Missouri and upper Mississippi valleys consist mainly of the dust from river silt that has been left on the dried mud banks in times of low water.

W. J. McGee considers the loess of Iowa as a glacial silt that was deposited along the margin of glaciers during the glacial period. W. F. Hume regards the Russian loess as glacial silt that has accumulated in part by the agency of the winds and in part by floods. T. C. Chamberlin considers certain loess to be derived from both glacial and eolian influences.

Geological Horizon.—Clays belong to the younger geological formations. They range from the Carboniferous to the Pleistocene.

PHYSICAL PROPERTIES

The physical properties that effect the commercial values of clays are plasticity, fusibility, color, slaking, tensile strength, air shrinkage and fire shrinkage.

Plasticity.—Plastic clays form a pasty mass when mixed with the proper amount of water so that they may be molded into any desired shape. They retain their shape when burned. A clay may be too plastic or fat to work well. Sand must then be added to decrease the plasticity. A clay may also be too lean for commercial purposes without the addition of some highly plastic clay. Ground shales are not as plastic as clays derived from the same shales by the disintegrating agents of the atmosphere for grinding does not thoroughly disintegrate the shale.

Plastic clays have great efficiency in the absorption of water. Nonplastic or lean clays are inferior in this respect. The plasticity of clays is due to the colloidal substances they happen to contain. The colloids, or hydrogels, hydroxides of alumina and iron, are common constituents. Similar hydrogels of manganese and copper oxides are frequently present. The colloidal com-

plexes of aluminum and iron silicates and humus behave in much the same manner.

Fusibility.—The fusibility of clays depends in a large degree upon the amount of fluxes they contain. These are generally lime, magnesia, oxides of iron, and various alkalies. The size of the individual grains in the clay enters into the problem. Other things being equal fine grained clays will fuse at lower temperatures than the coarse grained clays. Common brick clays will fuse at temperatures varying from 1,090 to 1,250 degrees C. The range of fusion of stoneware clays falls between 1,410 and 1,510 degrees C. Fire clays become viscous between 1,750 and 1,790 degrees C. The fusibility of any clay can be determined by comparison with the fusion points in the standard set of Segar cones. This set consists of 58 cones which range in fusion from 590 degrees C. to 1,850 degrees C.

Color.—The color of clays is not always a safe guide as to commercial value. Clays colored red and brown by the oxides and hydrous oxides of iron suggest a low fusion point, for these oxides serve as fluxing material in the burning of the clay. Black clays free from an iron content or with only a small amount of iron, will burn white or a creamy white. If the iron oxides are present in appreciable quantities even black clays will burn red. Clays containing large quantities of organic matter may be slowly burned into satisfactory bricks.

Slaking.—This is the property a clay possess of falling apart when thrown into water. The more rapidly a clay slakes the more readily it can be mixed and the more easily it is washed. Washing is often necessary by mechanical means to free a clay from injurious constituents. Dense clays slake slowly. Many shales refuse to slake when thrown into water but disintegrate completely upon sufficient exposure to the atmosphere.

Tensile Strength.—This property expresses the resistance to rupture that air dried clays will exhibit. Plastic clays usually show a higher tensile strength than lean clays. A high tensile strength enables a clay to resist cracking while in the process of drying. It also withstands harder usage.

Clays and shales show a wide variation in their cohesiveness on account of the variations in their mineral composition. Sandy clays as well as kaolins are usually of low tensile strength. The tensile strength of different kinds of clays is here given to show this wide range. The strength is stated in terms of pounds per square inch.

Lb. Per Sq. In.

Kaolins 5- 20
Paleozoic shales 60- 80
Brick clays 80-150
Pottery clays 150-200
Very plastic clays 200-400

The tensile strength of clay is determined in the same manner as the tensile strength of cement. The clay is fashioned into briquettes which are then air dried in a warm room and subsequently broken in testing machines. If the briquettes are not uniform in size and different methods are employed in drying the results obtained may be misleading.

Air Shrinkage.—This term refers to the decrease in size of a given mass of clay during the process of air drying. It is the loss in volume sustained by clays during the evaporation of the water used in mixing the material. The percentage of air shrinkage stands in direct relation to the amount of water absorbed by the clay in the process of mixing and tempering. The amount of absorption depends upon the plasticity of the clay. The more plastic the clay the more water it absorbs and therefore the greater will be its air shrinkage. Some lean or sandy clays show only from 1 to 2 per cent of shrinkage while plastic clays vary from 8 to 10 per cent.

Clays may be either too lean or too fat for commercial purposes. The more sandy clays need to be mixed with some highly plastic clay. Clays that are too plastic need the addition of some sandy material. The practical problem is to secure the clay that will show the proper air shrinkage. The greater the decrease in volume during drying the greater is the danger of the various products cracking or warping. Products manufactured from highly plastic clays must be dried carefully and slowly to prevent these ill effects. The ideal clay or mixture of clays will have a low air shrinkage and will withstand rapid drying. The drying will begin by the evaporation of the mixing water as soon as the molded product is taken from the machine. It is not all evaporated before the products are placed in the kiln for burning. The last of the mixing water is expelled during the early stages of burning the products. The large quantities of water vapor often seen issuing from the chimneys of kilns represent a part of the water used in mixing the materials and not the water of crystallization in the particles of kaolinite in the clay. The process of expelling the water is known as water-smoking.

Fire Shrinkage.—Fire shrinkage is the decrease in volume that clay products undergo during the process of burning in the kiln. It occurs after all of the water and carbon dioxide have

been expelled. It commences at the time the various products reach a dull redness. Sandy clays show a fire shrinkage varying from 2 to 3 per cent and highly plastic clays from 15 to 20 per cent. Fire shrinkage in clay products may be diminished by the addition of sand to the mixture. If too much sand is added the products may expand at high temperatures.

CHEMICAL COMPONENTS

The manufacturer of clay products considers the physical properties of clays of far greater significance to him than the chemical composition. The former are capable of easy interpretation by him while he fails in many cases to utilize facts revealed in chemical analysis. The analysis is always of value. It is of greater significance in high grade clays.

The quantitative analysis reveals the percentage of silica, alumina, ferric and ferrous oxides, lime, magnesia, potash and soda present in the clay. Titania, manganese oxide, phosphoric acid and sulphuric acid are often present in small quantities and not always determined in the ordinary quantitative analysis. The former list of clay constituents either increases or decreases the fusibility of the clay products according to whether they are fluxing or nonfluxing materials. Iron oxides, lime, magnesia, potash and soda are regarded as fluxing materials, while silica and alumina are refractory or nonfluxing constituents.

Kaolinite.—This mineral, which is a hydrated silicate of aluminum, is regarded as present in varying proportions in all clays. It is infusible before the blowpipe for it is highly refractory. Its fusion is easily effected in the presence of fluxes.

Silica.—The silica present in clays comprises (1) Free silica, or quartz particles. (2) The silica combined with the bases as represented by the feldspars, micas, amphiboles, pyroxenes and garnets whose finely comminuted fragments remain in the various clays. (3) The silica contained in the hydrous silicate of aluminum, kaolinite.

The free quartz or true sand is present in varying proportions in all clays. It is insoluble in the mineral acids and practically insoluble in caustic alkalies. At low temperatures it is refractory, but at high temperatures in the presence of alkalies it is a fluxing material. Its presence diminishes the air shrinkage, fire shrinkage and plasticity of clays, while its tendency is to increase the porosity of the finished products. The anhydrous silicates are often grouped with the sand and incorrectly called free silica.

Alumina.—The alumina in clays is of two kinds. (1) The alumina combined with the silica in the feldspar, micas, aluminous

amphiboles and pyroxenes together with the alumina in the garnets. (2) The essential alumina in the kaolinite particles. The aluminum silicates present in the clays may be regarded as refractory or nonfluxing constituents.

Iron.—Iron bearing minerals are common constituents in ordinary clays. The most prevalent iron minerals are hematite, limonite and their homologs. Iron may be present as a silicate wherever grains of glauconite or garnets appear in the clays. It is found in some clays as the carbonate, siderite, and in clay iron concretions. It may also appear as the sulphide, pyrite, and as a phosphate in vivianite.

The function of the iron particles in the clay is two-fold. (1) They all serve as a flux and therefore lower the fusion point of the clays containing them. (2) They serve as coloring agents, not only for the clays before molding but in the color of the finished products.

Hematite imports a red color to the original clays. Limonite a reddish brown or even a yellow color, depending upon the degree of hydration of the iron and the amount of the hydrated oxides present. Minute grains of pyrite, although a pale brass yellow themselves, tend to produce a gray. When grains of vivianite become sufficiently abundant the color is a bluish gray. Glauconite grains tend to produce a green coloration in clays and shales. The green color of the Vernon shales of central New York is due in part to the presence of glauconite.

The presence of the oxides and the hydrous oxides of iron in moderate amounts in clay is not objectionable unless a white or creamy white ware is desired. Pyrite is an objectionable constituent for it yields sulphuric acid in the process of burning. This tends to make the finished products poor. If present as crystals or granular masses these should be extracted before the clay is molded. If not extracted the clay should be finely crushed so as to reduce all lumps bearing pyrite to a fine state of subdivision else the lumps will melt, swell and throw off pieces of the ware during the process of burning. Whenever iron is present in the clay as the mineral siderite, or as clay iron concretions bearing manganese, these should also be removed from the clay either in the process of mining or in preparing the clay for mixing. The presence of these concretions in the molded products tends to form blisters during the process of burning.

In whatever compound the iron is present in the original clay it will be converted into the ferric condition, if not ferric before burning, during the process of burning. This holds especially true when the atmosphere of the kiln is free from smoke so that

it becomes an oxidizing agent. During the later stages of burning a part of the iron, if not all, unites with other elements in the formation of complex silicates.

In the process of burning iron bearing clays small quantities of iron tend to produce a buff colored product. Large quantities of iron in the clay will produce a red coloration. The intensity of the color is affected by the higher temperatures. When clays are rich in iron content they are often limed until the lime is in excess of the iron in order that a buff colored product may be obtained.

Lime.—Lime is present in some form in nearly all clays. It is usually derived from the common minerals calcite and dolomite. In rare cases it may have been derived from labradorite, a hornblende, augite and even garnet. Its presence serves as a fluxing agent in the burning of the products. It increases the rate of softening of the clay under fire. It destroys the red color normally imparted by iron to various wares. Its presence can be easily detected by effervescence with dilute HCl.

The form in which calcium carbonate is present in clays is a matter of considerable importance. When it occurs in a fine state of subdivision it is not injurious for many purposes. When it occurs in lumps or pebbles it should either be removed in the mining of the clay or finely crushed and intimately mixed with the clay before molding and burning. When present in lumps the expulsion of the carbonic acid during the process of burning produces blisters in the ware. These aggregations may also absorb moisture after the product has been burned and thereby split off particles of the ware.

Calcareous clays bearing 20 per cent or more of carbonate of lime may be used in the manufacture of common brick, earthen ware, drain tile and terra cotta. They are not suited for the manufacture of paving brick, stone ware, sewer pipe or vitrified ware in general. Calcareous clays are used to a considerable extent in the manufacture of Portland cement.

Magnesia.—Fuller's earth includes many varieties of unctuous clays of gray and dark green color. It is only in part Breithaupt's smectite which sometimes carries 4.89 per cent magnesia. Kaolinite is a common constituent in these clays. Save in fuller's earth all varieties of clay bear an inappreciable quantity of magnesia. The objections to large quantities of magnesium carbonate are the same as those mentioned for similar quantities of calcium carbonate.

Alkalies.—This term includes the salts of both potash and soda. They are present in nearly all clays. They are most fre-

quently derived from various members of the feldspar or mica families. All orthoclase and muscovite are rich in potassium. Albite is the feldspar with the highest percentage of sodium. The alkalies of some residual clays have been attributed in part to various amphiboles, pyroxenes and even garnets. The presence of these alkalies as necessary constituents of feldspathic grains serves as a fluxing agent. Some feldspar is usually added to kaolin in the manufacture of porcelain, earthenware and other wares burning to a white dense body. Albite is often added to white kaolinite in the manufacture of pure white porcelain. The alkalies, however, do not influence the color of the finished product. It is rather the impurities in the kaolin that play this role.

Titanium Dioxide.—Rutile, TiO_2, is rather widely scattered in minute grains or crystals in both igneous and sedimentary rocks. As it is insoluble, and in the highest state of oxidation for titanium, these particles appear in minute quantities in many clays, but nowhere in a quantity to warrant extraction of the titanium content. Small quantities of titania are often added to produce an ivory tint in porcelain.

Manganese Oxide.—Manganese frequently appears in minute quantities in clays. Its presence may be attributed to the decomposition of manganese-bearing silicates. In these minute quantities that are not determined in many analyses of clays it is not injurious. The greatest danger appears to be when it is present in the clay iron concretions and these nodular masses are not removed in the mining of the clay or crushed finely before mixing the clay for molding. The ill effect of these nodules has already been cited under the caption of iron. Small quantities of manganese oxide can produce a violet tint, larger amounts a brown, while an excess will produce a jet black coloration as seen in door knobs.

Sulphuric Acid.—This product is derived from the burning of clays rich in sulphides and the resulting wares are always poor.

Water.—There are two kinds of water in all clays. (1) Hygroscopic moisture which is mechanically mixed with the clay grains. (2) Water of combination which is essential in all kaolinite. Shales usually contain only a small percentage of mechanically combined water, while some clays carry from 30 to 40 per cent of hygroscopic moisture. The expulsion of this moisture during the process of air drying is accompanied with a shrinkage of the mass. Its complete expulsion is effected during the early stages of burning the products in the kiln. Air shrink-

age ceases when all the particles are brought in contact with each other.

Hygroscopic moisture may be injurious in clays for two reasons. (1) It may dissolve soluble salts contained in the clay and bring to the surface an undesirable efflorescence, or white coating. (2) If this moisture is expelled too rapidly in the process of burning the ware will blister.

Chemically combined water is present in all clays. Pure kaolinite bears 14 per cent of such water. Its presence is further due to the hydrated oxides of iron and to hydrous silicates that happen to be present in the clay. It is liberated only at a red heat and is accompanied with a second shrinkage in the mass.

Organic Matter.—Varying amounts of organic matter are usually present in transported clays. It comprises the finely divided plant tissues, and in some instances larger portions of plant remains, that have suffered deposition along with the clayey matter. The presence of organic matter affects the clay in three ways. (1) It affects the color of the clay, or shale. (2) It reduces its plasticity. (3) It lowers its power of absorption. The presence of organic matter does not affect the color of the finished products for it is usually all consumed in the process of burning the various wares. In some cases a vitrified zone forms around the center which still contains the carbon. The carbon thus encircled may continue to burn and liberate gases which bloat the brick. If the burning is not accompanied with a temperature sufficiently high to bloat the brick then there remains within the brick a black core.

Chemical Analysis. — A few analyses are appended as a matter of reference. They throw but little light on the behavior of clays in the process of manufacture of the various wares, save where the percentage of impurities becomes especially pronounced.

1. Analysis of a typical sample of orthoclase.

Silica, SiO_2 .... 64.6%
Alumina, Al_2O_3 .... 18.5
Potassa, K_2O 16.9
                                      ─────
                                      100.0

2. Analysis of a typical kaolinite.

Silica, SiO_2 .... 46.2
Alumina, Al_2O_3 .... 39.8
Water, H_2O 13.9
                                      ─────
                                      99.9

3.   Analysis of a typical pholerite which stands next to kaolinite in importance amongst the hydrous silicates derived from the decomposition of orthoclase.

Silica, SiO_2 .... 39.3
Alumina, Al_2O_3 .... 45.0
Water, H_2O 15.7
                                    ———
                                    100.0

4.   This analysis represents the composition of a residual clay from Greenville, Georgia.   The analysis is taken from Bulletin 9, Georgia Geological Survey, p. 315.   This clay was derived from granite.

Silica, SiO_2 .... 51.29
Alumina, Al_2O_3 .... 29.69
Ferric oxide, Fe_2O_3 .... 6.33
Ferrous oxide, FeO, and Lime, CaO... 0.07
Magnesia, MgO 0.14
Potassa, K_2O 1.50
Soda, Na_3O 1.12
Combined water, H_2O 10.36
                                    ———
                                    100.50

5.   Number 5 represents the average of four analyses of residual clays from shale from Hot Springs, Arkansas.   The analysis was made by George Steiger and taken from Bulletin 285, U. S. Geological Survey, p. 409.

Silica, SiO_2 .... 71.91
Alumina, Al_2O_3 .... 16.24
Iron oxide, Fe_2O_3 .... 1.79
Lime, CaO 0.18
Magnesia, MgO 0.88
Alkalies, K_2O, Na_2O 3.27
Combined water, H_2O 4.39
                                    ———
                                    98.66

6.   Analysis of residual clay derived from limestone, Morrisville, Calhoun County, Alabama.   The analysis is taken from Bulletin 52, U. S. Geological Survey, p. 40.

Silica, SiO_2 .... 55.42
Alumina, Al_2O_3 .... 22.17
Iron oxide, Fe_2O_3 .... 8.30
Lime, CaO 0.15
Magnesia, MgO 1.45
Alkalies, K_2O, Na_2O 2.49
Water, H_2O 9.86
                                    ———
                                    99.84

7. Analysis of a marine clay from Thomaston, Maine. The analysis was made by W. T. Schaller.

Silica, SiO_2 .... 62.80
Alumina, Al_2O_3 and small amounts of
    titanic acid, TiO_2 .... 18.23
Iron oxides, Fe_2O_3, FeO 6.40
Lime, CaO 0.88
Magnesia, MgO 1.58
Potassa, K_2O 3.05
Soda, Na_2O 1.46
Combined water, H_2O 4.39
Moisture 1.31
                            —————
                           100.10

8. The following analysis of a stream clay from Catskill, New York, is taken from Bulletin 35, New York State Museum, p. 702.

Silica, SiO_2 .... 52.73
Alumina, Al_2O_3 .... 22.25
Iron oxides, Fe_2O_3, FeO 7.69
Lime, CaO 1.48
Magnesia, MgO 3.20
Potassa, K_2O 4.28
Soda, Na_2O 2.22
Carbon dioxide and combined water... 4.91
                            —————
                           98.76

9. Analysis of loess clay from St. Louis, Missouri. Analysis quoted from Building Stones and Clays, E. C. Eckel.

Silica, SiO_2 .... 73.92
Alumina, Al_2O_3 .... 11.65
Iron oxide, Fe_2O_3 .... 4.74
Lime, CaO 1.43
Magnesia, MgO 0.60
Alkalies, K_2O, Na_2O 3.13
Combined water, H_2O 3.08
                            —————
                           98.55

MINING AND WASHING CLAYS
MINING

The methods utilized in mining clay and shale are essentially the same. Where the deposits are large and the clays of uniform texture and composition the process is simple. If the clays are shallow, of limited distribution and of many varieties the process may be rendered somewhat complex.

There are two quite different methods of mining the clays. (1) Quarrying, open-pit work as it is sometimes called. (2) Underground working.

Quarrying.—The method often observed by the writer at the smaller brick plants in northern New England is to remove the soil overlying the clay by means of a spade and wheelbarrow, or in larger deposits with a span of horses and a scraper. The clay is then quarried by means of a pick and shovel. The work is open cut as in quarrying building stones. (See Fig. 265.)

There are often several different benches of the clay which are being mined or quarried at the same time. Their appearance is not altogether unlike the effect produced in a granite quarry by the different sheets of granite on the different levels of the quarry floor. This method is employed in the majority of the clay working industries of the United States. It is applicable in all cases where the deposits are shallow, where they are of somewhat limited extent, where the use of a steam shovel is impractical and where the clays vary in composition so that they can not be advantageously mixed. (See Fig. 266.)

Wheel Scraper.—The wheel scraper is used to advantage in many cases where the clays permit mixing and where they are sufficiently soft to be easily worked.

Steam Shovel.—The steam shovel which can be operated at a low cost when constantly in service, is utilized where the clay deposits are of large extent and where they are of sufficient uniformity in composition to permit mixing. Steam shovels are in common use in working the clays and shales of Carboniferous age in Indiana, Ohio and Pennsylvania.

Open Pit.—This method is applicable to kaolinite deposits that are in the form of veins. Circular pits are sunk from 50 to 75 feet and cribbed. After the kaolinite has all been mined out

Fig. 265.—Brick yard, kiln and drying sheds, St. Johnsbury Center, Vermont.   Photo. by C. H. Richardson.

Fig. 266.—Cretaceous clay bed, Woodbridge, New Jersey.   By courtesy of the U. S. Geological Survey.

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the pit is filled with waste and the cribbing removed as the filling proceeds. A second pit is sunk in the same manner and the process continued until the entire vein of kaolinite has been mined out. The clay is raised from the pit in buckets. In a few instances the clay is so sandy that it has to be washed. In such cases it can be agitated with water in the pit and then pumped to the clay plant. (See Fig. 267.)

Undermining.—In come cases the clay deposit is undermined for many feet along the floor of the quarry. A series of wedges may be driven into the clay a few feet above the quarry floor and
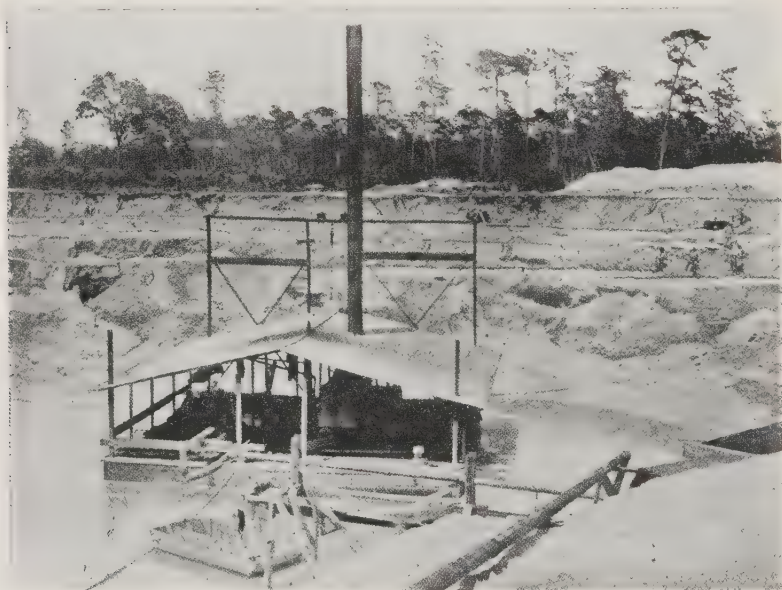
Fig. 267.—Ball-clay pit at Edgar, Florida. By courtesy of the U. S. Geological Survey.

small blocks of clay broken down. Generally, however, the wedges are driven into the clay bed from the top of the formation and large blocks are split off from the working face at little expense. These blocks are broken up as they fall on the quarry floor.

UNDERGROUND MINING

Beds of clay or shale are often overlain with many feet of solid rock whose removal would be exceedingly expensive. The clay

or shale beds may or may not appear at the surface. Their edges or ends may be covered with talus material or in the more northern areas with glacial debris. The position of the beds may vary from horizontal to vertical.

Drifting.—This method is applicable where the edges of the clay or shale bed appear at the surface in a horizontal position or when the angle of slope is not too high. Drifts are extended along the clay bed in the direction of the strike. Drifts are also made upon either side of the main line and extended outwards to the ends or edges of workable clay or shale deposits. The general appearance of this branching drift is quite similar to the vast network of drifts seen in the anthracite coal mines of Pennsylvania and in other mines elsewhere.

A modification of this method is introduced where the angle of emergence is high. It is perhaps a combination of the shaft and drift method. In a few cases the beds are highly folded with the interstratified sedimentaries or tilted to an angle of nearly 90 degrees. The clay is removed without disturbing the interbedded rocks.

Shaft.—Where clay or shale beds do not outcrop at the surface a shaft is sunk until the clay or shale is encountered. Drifts are then extended in various directions to the ends and edges of the workable stratum of clay or shale. The material mined is raised from the foot of the shaft as ore is raised from a mine. It sometimes happens in the Carboniferous clays or shales that there is more than one stratum of clay and more than one bed of coal. In such cases the coal is mined and used as a fuel at the brick plant.

Haulage.—The simplest known method of transportation of clay to the plant is by wheelbarrows. This method is still applicable where the tonnage is small and the clay beds themselves are in close proximity to the brick plant. Where the tonnage becomes considerable, and the distance of the clay beds from the brick plant makes the former method impracticable, carts drawn by mules or horses have been introduced. This may be effected either over a normal road or a temporary railway. Sometimes the loaded cars are run to the plant by gravity and the empties returned by mules. Steam haulage is applicable where the clay beds are large, the distance of haulage long and the output of the factory steady. Aerial tramways have been introduced in some cases to transport the clay or shale from beds at the higher altitudes to the manufacturing plant at the lower altitudes. In this case the loaded bucket returns the empty one to the mine.

PREPARATION OF CLAY

There are several well known methods of preparing clays for mixing and molding. Clays are frequently so impure as they come from the mine that some step in this direction becomes necessary.

Crushing.—In certain cases the clays as they come from the mine are crushed so as to reduce all pebbles contained in the clay as well as the clay itself to an impalpable powder. The process does not necessitate the drying of the clay. Where clays are not crushed, screened or separated in any manner the small pebbles they contain often render the exterior of brick uneven and the output of the plant unsatisfactory.

Screening.—Screening usually necessitates a previous drying of the clay. Its purpose is to remove all pebbles of limestone, lumps of pyrite, concretions of clay iron stones and all other aggregations of matter too large to pass through the screens. If these impurities are not removed their effect is very deleterious on the finished product.

Washing.—The object in washing clay is to remove the sand and pebbles from the clay before mixing and molding. The following methods of washing are taken from Bulletin Number 35, New York State Museum.

Circular Tubs.—In this process the clay is thrown into large circular tubs filled with water, in which it is stirred by revolving arms and the clay lumps thereby disintegrated. By this treatment the fine grains of kaolinite, mica, feldspar and quartz remain suspended in the liquid, while the coarser grains settle to the bottom of the tank. The water containing the suspended clay is drawn off into settling tanks.

A modification of this process consists in the use of a large cylinder closed at both ends. It is set in a horizontal position and contains an axis with iron arms whose revolutions break up the clay. The clay is fed into the machine through a hopper at the top. A current of water passes through the cylinder and carries away the finer clay particles while the coarser material is left behind in the machine. If the current employed is too slow the clay will not yield a sufficient percentage of washed product. If the current is too rapid some of the coarse material will be washed out of the cylinder. The chief objection to this method is that the apparatus has to be stopped from time to time to remove the coarse sand and pebbles from the machine.

Log Washing.—The apparatus consists of a semicylindrical trough in which revolves a horizontal axis with short arms. The

arms break up the kaolin more or less according to its density and facilitate the subsequent washing. The stream of water directed into the log washer sweeps the kaolin and most of the sand into the washing trough. This trough is about 15 inches wide and 12 inches deep, but should be wider and deeper if the clay is very sandy.

The washing trough has a pitch of 1 inch in 20 feet, but the amount of pitch should depend on the kaolin and whether the contained sand is fine or coarse. The finer the kaolin the more slowly it will settle and the lower will be the pitch of the trough. The water is conducted from the trough into settling vats. As a further and necessary precaution it is discharged on a 100 mesh screen to remove any coarser particles that might remain together with all bits of wood and floating dirt.

Stationary Screens. — The stationary screen consists of a frame covered with copper cloth and set at a slight angle. The water and suspended kaolin pass through the screen. Sometimes two or three screens which overlap each other are used so that whatever kaolin does not fall through the first may be caught later on the other screens. Stationary screens are likely to clog with vegetable matter and pieces of wood and therefore must be closely watched.

Revolving Screens. — Revolving screens are the most satisfactory, for they are self-cleansing. They are barrel-shaped and the water with the suspended clay is charged into the interior and passes outward through the screen cloth. As the screen revolves the dirt is carried upward and dropped on a board which diverts it to the ground.

Settling Tank.—The settling tank into which the water and suspended kaolin falls is usually about 50 feet long, 8 feet wide and 4 feet deep. As soon as one is filled the water is diverted into another. The larger the tanks the more uniform will be the marketable product. If the kaolin settles too slowly a little alum is sometimes added to the water to hasten the deposition. When the kaolin has settled most of the clear water is drawn off. The creamlike mass of kaolin and water in the bottom of the vat is drawn off by means of slip pumps and forced by these into the presses.

Presses.—The presses consist of flat iron or wooden frames between which are flat canvas bags. These bags are connected by ripples with a supply tube from the slip pumps, and by means of pressure from the pumps nearly all of the water is forced out of the kaolin through the canvas. When as much water as possible is squeezed out the press is opened and the sheets of semi-

dry kaolin are taken out. The product is then dried either on racks in the open air or in a steam heated room.

Yield.—Every ton of crude kaolin should yield from one-fourth to two-fifths of a ton of washed kaolin. The washing plant should be located if possible at the mines to avoid the transportation of 60 or 70 per cent of waste sand which has to be washed out before the kaolin can be used or placed on the market.

Cyclonic Separation.—This process consists of feeding the clay in a dry state into a pulverizer which reduces the kaolin to a powder. The material is discharged from the pulverizer into a box or tunnel and the finer particles are carried upward by cyclonic currents of air to the end of the airway, where they are dropped into storage bins. The heavier particles fall back into the crusher. The method is applicable to kaolins that are free from pyrite and siderite or clay iron concretions.

EMPLOYMENT OF CLAYS

Value.—Most clays are manufactured into clay products by corporations or individuals directly concerned in mining them. Some kaolins, fire clays, ball clays, paper clays, pottery clays and terra cotta are sold by the ton either f. o. b. or at the market. The price ranges from 50 cents a ton for some pottery clays to $12 per ton for washed kaolins. The price of fire clays varies from $1 to $2 per ton. Paper clays vary from $7 to $10 per ton.

In the examination and estimation of the value of any clay deposit not only must all of the physical and chemical characteristics be called into question but also the structure and mode of occurrence must be considered. It is also necessary to work out by means of the clay auger the tonnage of the deposit and determine the market value for that particular kind of clay.

Uses.—The following summation of uses was worked out by R. T. Hill for the Mineral Resources of the United States in 1891 and modified by H. Ries in his Professional Paper Number 11, U. S. Geological Survey.

Domestic.—Porcelain, white earthen ware, stone ware, yellow ware and Rockingham ware for table service and cooking; majolica stoves; polishing brick, bath brick and fire kindlers.

Structural.—Brick; common, front, pressed, ornamental, hollow, glazed, adobe, terra cotta; roofing tile; glazed and encaustic tile; drain tile; paving brick; chimney flues; chimney pots; doorknobs; fireproofing; terra cotta lumber; copings; fence posts.

Hygienic.—Urinals, closet bowls, sinks, washtubs, bathtubs, pitchers, sewer pipe, ventilating flues, foundation blocks, vitrified brick.

Decorative.—Ornamental pottery, terra cotta, majolica, garden furniture, tombstones.

Minor Uses.—Food adulterant, paint fillers, paper filling, electric insulators, pumps, fulling cloth, scouring soap, packing for horses' feet, chemical apparatus, condensing worms, ink bottles, ultramarine manufacture, emery wheels; playing marbles; battery cups; pins, stilts and spurs for potter's use; shuttle eyes and thread guides; smoking pipes; umbrella stands; pedestals; filter tubes; caster wheels; pump wheels.

Refractory Wares.—Crucibles and other assaying apparatus; gas retorts; fire bricks; glass pots; blocks for tank furnaces; saggers; stove and furnace bricks; blocks for fire boxes; tuyeres; cupola bricks.

Engineering Works.—Puddle; Portland cement; railroad ballast; water conduits; turbine wheels.

According to Jefferson Middleton in the report of the clay working industry of the United States for 1914 the value of the clay products for that year in the United States was $164,986,983. Brick and tile represent a value of $129,588,822, and pottery $35,398,161. The average annual value of clay products from 1910 to 1914 was $170,287,909. In 1914 clay products were manufactured in every state. The territories, Alaska and Hawaii, reported no production.

Ohio has maintained the rank of the leading producer ever since figures were first compiled by the Geological Survey in 1894. The production in Ohio in 1914 was valued at $37,166,768. Pennsylvania's output was valued at $21,946,996. New Jersey, $16,484,652. Illinois, $13,318,953. New York, $9,078,933.

For a more complete description of clays see the important publications of Prof. H. Ries as listed in the references on page 344.

REFERENCES

Baker, Ira O., A treatise on Masonry Construction; John Wiley and Sons, New York, 1913.

Bleininger, A. V. The Effect of Heat upon Clays; T. A. Randall and Co., Indianapolis, Indiana.

Crossley, A. Tables of Analyses of Clays; T. A. Randall and Co., Indianapolis, Indiana.

Eckel, E. C. Building Stones and Clays; John Wiley and Sons, New York, 1912.

Griffen, H. R. Clay Glazes and Enamels; T. A. Randall and Co., Indianapolis, Indiana.

Richardson, N. D. Kiln Records; T. A. Randall and Co., Indianapolis, Indiana.

Ries, H. The Clays of the United States East of the Mississippi River; U. S. Geol. Survey, Professional Paper No. 11, 1903.

Ries, H. Clays: Their Occurrence, Properties and Uses; John Wiley and Sons, New York, 1908.

Ries, H. Building Stones and Clay Products; John Wiley and Sons, New York, 1912.

Ries, H., and Henry Leighton, History of the Clay-Working Industry in the United States; John Wiley and Sons, New York, 1913.

CHAPTER X

BUILDING BRICK

Common Brick.—The ordinary clays and shales are used in the manufacture of common brick. Whatever the color of the original clays may have been the most of the brick burn red. Many of the clays of Illinois, Michigan and Wisconsin burn to a creamy white product because the clays are rich in lime. The drab and bluish glacial and terrace clays of New England have given rise to many brick homes that are fairly permanent. The brick are often manufactured near the site where the house is erected. Fig. 268 represents a house built from glacial clays in Calais, Vermont, in 1815. (See Fig. 268.)

The requisites for common clays are that they shall mold easily and burn to a hard product at comparatively low temperatures.

Pressed Brick.—These are usually manufactured from the higher grade clays. The clays may be classified according to the color of the burned products. (1) Red-burning clays. (2) Buff-burning clays. (3) White-burning clays.

The requisites for pressed brick clays are as follows: (1) The clays must burn to a fairly uniform color. There is a considerable deviation from this demand at the present time. (2) Freedom from warping and splitting. (3) Absence of soluble salts in the clays. (4) The burned product must be sufficiently hard for structural purposes. (5) The absorption of the finished product must be low. (See Fig. 269.)

Enameled Brick.—The clays used in the manufacture of buff pressed brick are well adapted for the manufacture of enameled brick. As the name implies the brick is covered with an enamel which conforms to the clay body to prevent scaling or cracking.

Fire Brick.—Fire brick are manufactured from nearly pure clays, or from pure clay and clean sand, or from nearly pure silica cemented with a small amount of clay. Clays designed for the manufacture of fire brick must contain less than 6 per cent of the oxides of iron and less than 3 per cent of combined calcium, magnesium, sodium and potassium minerals. Pyrite is perhaps the most objectionable mineral ever present in fire clays.

Fire brick are designed for use whenever high temperatures are to be resisted. Such brick should be uniform in size, regular

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Fig. 268.—Brick house built in Calais, Vermont, in 1815, with brick manufactured from glacial clays.   Photo. by C. H. Richardson.

Fig. 269.—Castle of St. Angelo, Rome, Italy, built of brick in 62 B. C. In the foreground is the famous brick bridge Pons Fabricius, which has withstood floods, earthquakes and conflagrations all the intervening centuries.   By courtesy of T. A. Randall and Company.

in shape, homogeneous in texture, uniform in composition, easily cut, strong and infusible.

Molding.—The slow and laborious method of pressing plastic clays by hand into various molds is now supplemented by a great variety of machines for preparing and molding the clays. (1) The soft-mud machine. The clay is reduced to a soft mud by adding about one quarter of its volume of water. (2) Stiff-mud machines. For this machine the clay is formed into a stiff mud. (3) Dry-clay machines. Here the dry clay, or clay that is nearly dry, is forced into the mold by heavy pressure without the

Fig. 270.—Immense strip bank of the Clay Products Company, Brazil, Indiana. By courtesy of T. A. Randall and Company.

reduction of the clay to a plastic state. In the filling of the molds there is sometimes a continuous stream of clay forced from the pug mill through a die and afterwards cut up into bricks. Again the clay is forced into molds moving under the nozzle of the pug-mill.

Burning.—The length of time that brick should be burned varies with the character of the clay, the form and size of the kilns, and the kind of fuel used. In the older process of burning, the brick when dry enough to handle are built up in arches. The eye of the arch runs through the entire kiln and in this the fuel for burning the bricks is placed. The whole stack is then covered

with a wall of green brick and all openings carefully plastered
up with mud. The drying and burning takes from 6 to 15 days.
The kiln is at first subjected to only a moderate heat but after
the moisture has been expelled the heat is increased slowly until
the bricks next to the eye of the kiln attain a white heat.   The
temperature is then kept nearly at a constant until the burning
is complete. All openings are then closed and the mass allowed
to cool slowly. (See Fig. 270.)

In the modern practice of burning the brick the principal
yards have permanent kilns. Rectangular spaces are surrounded,
save for very wide doors at the ends, by permanent brick walls
which have fire boxes on the outside. The circular kilns are
entirely enclosed with brick masonry. They are sometimes made
in separate compartments, each of which has a separate entrance
and an independent connection with the chimney. The latter
may be built within the kiln or entirely outside the kiln.   In
either case a downward draught is secured. Fine coal is placed
near the top of the kiln and the down draught causes a free
circulation of the flame and the heated gases about the material
being burned. The advantages of compartment kilns are that
while some are being burned others may be filled and still others
emptied. In Texas crude oil is often the fuel used.

Water Smoking.—In water smoking the fire of the kiln is
raised slowly and gradually to temperatures not exceeding 200
degrees C. The object of slowly expelling this hygroscopic
moisture is to prevent the fracture of the brick by the rapid
expansion of steam. Steam pressure may be sufficient to loosen
the bond of clay or produce fissures along the laminations. When
such brick are struck with a hammer they sound dead like a
fractured stone. The point when all the hygroscopic moisture
has been driven off may be determined by thrusting a cold rod
into the kiln flue. If the rod is moist upon withdrawal steam is
still coming off from the clay products. If the rod is dry the
process of water smoking is complete.

Dehydration and Oxidation.—These two steps in the burning
of clay products overlap each other and are therefore carried
on simultaneously. The former requires the expenditure of
heat while the latter produces heat. In dehydration the chemi-
cally combined water must be expelled from the brick and also
the carbon dioxide of the carbonates driven out of the various
wares. In oxidation the carbon and the sulphides must be burned
out and the ferrous iron oxidized to the ferric condition.

One method for determining the progress of dehydration
is to remove a brick from time to time and weigh it. As long

as the brick continues to lose weight the process of dehydration is incomplete. The proper practical dehydration temperature is not less than 650 degrees C. Pyrometers are now in general use in the brick industry.

The expulsion of the carbonic acid in the carbonates of lime and iron extends over a longer period of time. The two are expelled at approximately the same time. After the carbon dioxide has been expelled from the limestone grains the remaining lime is ready to serve as a fluxing agent. The iron
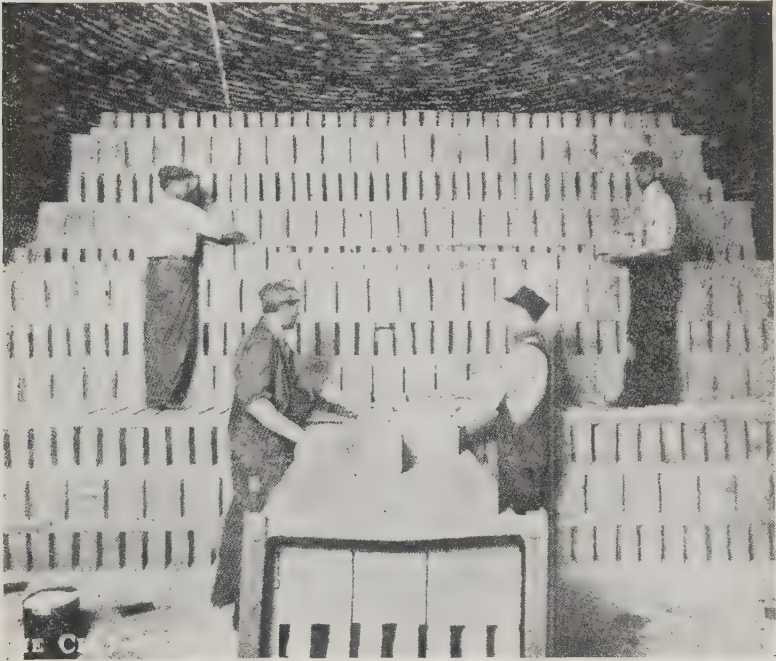
Fig. 271.—Setting a kiln of rough X brown brick. By courtesy of T. A. Randall and Company.

at the same time is in the ferrous condition and ready for oxidation. According to A. V. Bleininger the most favorable temperature for oxidation is 750 degrees C. And according to E. Orton 800 degrees C. The time required for complete oxidation varies from 4 to 7 days. (See Fig. 271.)

Vitrification.—This part of the process as the name implies leads to the formation of a glassy product, or tends to fuse the clay into a glass. The work begins during the last stages of oxidation and immediately thereafter. The first result is a

consolidation and hardening of the clay. Several different stages are noted in the process. (1) Earthen fracture stage. This is the one usually observed in common building brick. There is no glassiness observed and the color of the brick is a light red. (2) Incipient vitrification. The color of the brick is now a darker red. The crushing strength is raised from about 4,500 lb. per square inch to about 8,000. Burning is insufficient to permit the material to be used for paving purposes. (3) Dense vitrification. Here the pores are largely closed. The color is a dark chocolate brown. For many clays the maximum toughness is here reached. The fracture shows a dense, compact, but not a glassy surface. (4) Viscous vitrification. In this stage the ware becomes vesicular, sometimes deformed, while often it shows distinct kiln

Fig. 272.—Panoramic view of the stock yards of the Clay Products Company's plant, Brazil, Indiana. By courtesy of T. A. Randall and Company.

marks. (5) Fusion. This is the final step in complete vitrification.

Coloration.—According to H. A. Segar clays high in iron oxide, low in alumina and free from lime burn red in oxidizing gases. Clays high in iron oxides and lime but low in alumina burn buff. Clays fairly high in alumina but with about 3 per cent of iron oxide content burn buff. Clays high in alumina and low in iron burn to a white or light buff color. The colors actually imparted to clay products depend upon both the chemical composition of the clay itself and upon the character of the burning. Red burning always may be made to assume a black color by causing reducing conditions to prevail during the first stages of the burning. (See Fig. 272.)

Artificial Brick Colors.—With the exception of wall and floor tiles and some classes of terra cotta the various oxides of iron and manganese are used. Limonite may be mixed with the

original clay to produce the darker hues. Hematite has been added to produce the dark specks desired in flashed brick. Pyrolusite in the granular form is often added to give this effect.

A white coloration is produced by a mixture of white burning clays. A gray color by the use of small quantities of manganese pulp. Black is produced by a mixture of iron and manganese oxides with a small amount of cobalt oxide. A red color is obtained by burning a good clay rich in iron oxides. Buff and yellow colors may be produced by mixing lime with clays bearing iron. A brown color is obtained by burning a red burning

Fig. 273.—Post Office, Bradford, Pennsylvania, built of brick, Oscar Wenderoth, architect. By courtesy of T. A. Randall and Company.

clay with manganese and chrome oxides. Green colors are produced by the use of chrome oxide. A blue color can be obtained with small quantities of cobalt oxide.

Classification of Building Brick.—Building bricks are classified according to (1) The way in which they are molded. (2) Their position in the kiln while being burned. (3) Their form or use. (See Fig. 273.)

Classification According to Method of Molding. — Ira O. Baker in his Treatise on Masonry Construction gives the following classification:

Soft-mud Brick.—A brick made by placing soft clay in a mold. It may be molded either by hand or by machinery.

Stiff-mud Brick.—One molded by forcing a prism of stiff clay through a die and afterwards cutting it up into bricks.

Pressed Brick.—Usually a stiff-mud brick which has been subjected to a great pressure to render the form more regular and to increase its strength and density. A soft-mud brick after being partially dried may be re-pressed to improve its form and increase its strength and density.

Fig. 274.—Clay bank 14 feet deep, Bridgeton, New Jersey. By courtesy of W. W. Ridgely.

Slop Brick.—A brick made by hand with the molds dipped in water before filling the mold with clay. This is done to prevent the clay from sticking.

Sanded Brick.—Brick made by the soft-mud process where sand is sprinkled into the molds to prevent the clay from sticking.

Machine-made Brick.—The use of this term now is indefinite for practically all grades and kinds of brick are made by machinery.

Classification According to Position in Kiln.—Where brick are burned in up-draught kilns this classification becomes impor-

tant. With the new style of kilns and improved methods of burning, the quality is so nearly uniform throughout the entire kiln that the classification loses its significance.

Arch, or Clinker Bricks.—These brick form the top and sides of the arches in which the brick are burned. They are hard, brittle and weak.

Body, Cherry, or Hard Bricks.—These are taken from the interior of the kiln. They are the best brick of the entire burn.

Salmon, Pale, or Soft Bricks.—Those which form the exterior

Fig. 275.—General view of brick yard, Bridgeton, New Jersey. By courtesy of W. W. Ridgeley.

of the mass. They are under burned and too soft for ordinary use, save for filling. The terms salmon and pale refer to the color of the brick. There is no relation between color and strength and density.

Classification According to Use.—The form and use of bricks gives rise to several different terms.

Compass Brick.—A brick having one edge shorter then the other. Such brick are used in lining circular shafts, etc.

Feather-edge Brick.—Such bricks have one edge thinner than

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the other.   They are used in arches and often called voussoir brick.

Face Brick.—This term is usually applied to re-pressed brick possessing uniformity of size and color.   They are used in the face of the walls of buildings. (See Figs. 274, 275, 276, 277, 278, 279 and 280.)

Sewer Brick.—These are the smooth, regular and ordinary hard brick.

Paving Brick.—A vitrified clay block which is very hard and somewhat larger than ordinary building brick.   The term brick paving-block is in common use.

Fig. 276.—Machine room, Bridgeton brick works, Bridgeton, New Jersey. By courtesy of W. W. Ridgely.

Vitrified Brick.—Such brick are burned to the point of vitrification and then annealed or toughened by slowly cooling.   They were originally manufactured for paving purposes but now they are much used in building and engineering structures.

Tests for Building Brick.—Five tests are frequently applied to determine the quality of building brick. (1) Form. (2) Texture. (3) Absorptive power. (4) Resistance to compression. (5) Transverse strength.

Form.—The regularity of form usually depends upon the quality of the clay used and the method of burning the finished

product. Building brick should have plane surfaces, parallel sides, sharp edges and angles. In regularity of form re-pressed brick stands first; dry-clay brick, second; stiff-mud brick, third; and soft-mud brick, fourth.

Texture.—Good building brick should have a fine, compact and uniform texture. They should contain no fissures, sand seams, air bubbles, pebbles of any kind, or lumps of lime. They should give a clear ring when struck with a hammer. A dull dead sound suggests a flaw or fracture.

The relative value of any brick depends largely upon the character of the clay used in its manufacture and its compactness

Fig. 277.—Loaded kiln, Erickson's brick yards, Bridgeton, New Jersey. Photo. by H. K. MacPherson.

upon the method of molding. In compactness and uniformity of texture hand-molded brick stands first; machine-molded, soft-mud brick, second; machine-molded stiff-mud brick, third; and dry-clay brick, fourth.

Absorptive Power.—The absorptive power of building brick varies with the chemical composition of the clay used in the manufacture of the brick. There seems to be no close relation between the absorptive power and the strength of brick, or the loss of strength by freezing. Some vitrified brick will absorb only from 1 to 2 per cent of water. Some dry-clay or pressed brick will absorb only from 5 to 10 per cent of water, while

others will absorb from 30 to 35 per cent of their weight of water.

Compressive Strength.—The crushing strength of building brick is of far less importance than that of building stones. The brick are of much smaller dimensions than the stone used for structural purposes, the percentage of mortar is relatively higher, therefore, the strength of brick masonry depends largely upon the kind of mortar used in laying the brick.

The compressive strength of brick sent to the World's Columbian Exposition is given in Tests of Metals, etc., 1894, pp. 456-468. The highest compressive strength in pounds per square inch is here given, together with the state or country where the brick were manufactured.

	Lb. per Sq. In.
Arkansas	9,469
Florida	5,077
Idaho	22,561
Illinois	12,280
Iowa	12,269
Minnesota	7,402
S. Dakota	8,936
Utah	4,362
Washington	13,137
Wyoming	13,077
Japan	5,529
Sweden	22,955

Brick Building in 1914.—The United States Geological Survey is now striving to compile statistics that will annually show the relative progress in building operations in the chief cities of the United States.

According to figures already compiled the value of the new buildings in 113 cities for 1914 was $461,681,108. The value of the fire resisting buildings was $296,454,858. The value of brick buildings was $181,957,682. The value of wooden buildings was $165,226,250. Other fire resisting buildings than brick represented a value of $114,497,176.

These figures show that brick leads all other materials used for building purposes in these cities and that the total of new brick buildings exceeds the combined total of wooden buildings and fire resisting buildings other than brick. The advantages of building with brick may be tersely characterized as safety, economy, stability, comfort, beauty and satisfaction.

BRICK AND TILE PRODUCTION FOR 1915

According to Jefferson Middleton the total value of clay products marketed for 1915 was $163,120,232, as compared with $163,986,983 in 1914. The most prominent features in the industries may be tabulated as follows: (1) The large increase in production and the even larger increase in value of common brick in Cook County, Illinois, where the production was 739,173,000 brick. This region now becomes the rival of the New York

Fig. 273.—Burned brick at storage sheds, Bridgeton brick works, Bridgeton, New Jersey. Photo. furnished by the Bridgeton Brick Company.

portion of the Hudson River region. (2) The large increase in the production and value of fire brick. (3) The increase in value of front brick. (4) The large increase in value of clay products in Illinois and Pennsylvania. (5) The large decrease in value of sewer pipe. (6) The small increase in average price per thousand of common brick and the decrease in average price of other varieties of brick.

Common brick, as its name implies, is the most widely dis-

tributed of the clay products, being reported from every State and Territory except Alaska and Hawaii. Illinois was the largest producer of common brick in 1915 with a value of $6,870,990. This state was followed by New York, Pennsylvania, Ohio and New Jersey in the order named.

Fire brick ranks second amongst the brick and tile products. It was reported from 35 states in 1915. Pennsylvania ranked first with a value of $7,177,629, followed by Ohio, Missouri and Kentucky in the order named.

Vitrified brick or block, the third brick and tile product in value in 1915, was reported from 31 states. Ohio ranked first

Fig. 279.—Armory, Bridgeton, New Jersey, built of Bridgeton brick. Photo. furnished by the Bridgeton Brick Company.

with a value of $4,017,738, followed by Illinois and Pennsylvania in the order named.

Front or face brick is widely distributed, sales being reported from 42 states in 1915. Pennsylvania ranked first with an output valued at $2,631,795 followed by Ohio, Indiana and Illinois in the order named.

Draintile was reported from 36 states. Iowa ranked first with a value of $3,802,599, followed by Ohio, Indiana and Illinois in the order named.

Sewer pipe was reported from 27 states. Ohio ranked first

with an output of $3,719,790, followed by Missouri, Pennsylvania and California in the order named.

Fireproofing, including hollow building tile or block, was reported from 35 states. Ohio ranked first with a value of $2,172,701, followed by New Jersey and Iowa in the order named.

Architectural terra cotta was reported from 12 states in 1915. New Jersey ranked first with an output valued at $1,430,968, followed by Illinois and New York in the order named.

The rank of the first ten states, the value of the output and the percentage of the total value of clay products may be tabulated for 1915 as follows:
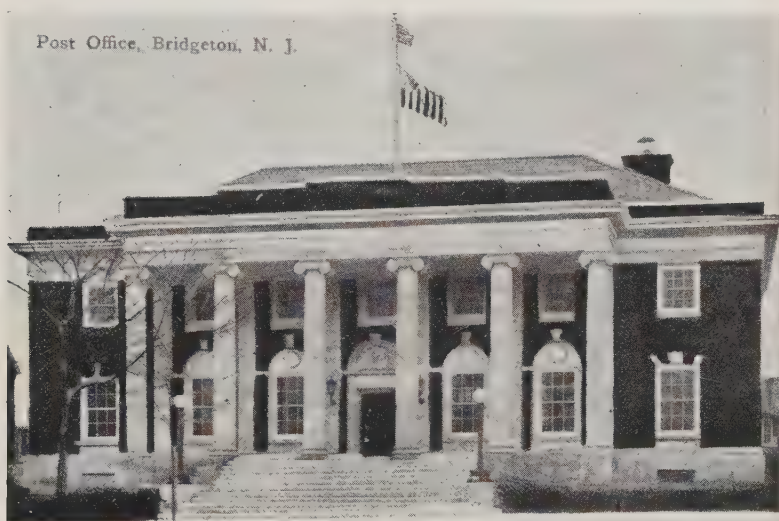
Fig. 280.—Post Office, Bridgeton, New Jersey, built of Bridgeton brick. Photo. furnished by B. W. Roberts.

Rank.	Value.	Percentage.
Ohio	$ 36,839,621	22.58
Pennsylvania	22,726,031	13.93
New Jersey	15,965,418	9.79
Illinois	14,791,938	9.07
New York	9,489,002	5.82
Indiana	7,090,630	4.35
Iowa	6,743,615	4.13
West Virginia	6,284,527	3.85
Missouri	5,431,569	3.33
California	3,599,375	2.21
All other states........	34,158,506	20.94
Total all states......	$163,120,232	

REFERENCES

Baker, I. O.   A Treatise on Masonry Construction; John Wiley and Sons, New York, 1913.

Bleiningers, A. V.   The Effect of Heat Upon Clays; T. A. Randall and Co., Indianapolis, Ind., 1911.

Hodson, F. T.   The 20th. Century Bricklayer's and Mason's Assistant; F. J. Drake and Co., Chicago, 1905.

Howe, M. A.   Masonry; John Wiley and Sons, New York, 1915.

Kidder, F. E.   Building Construction and Superintendence; Wm. T. Comstock, New York, 1906.

Munby, A. E.   The Chemistry and Physics of Building Materials; D. Van Nostrand Co., New York, 1909.

Ries, H.   Clay, Its Occurrence, Properties, and Uses; John Wiley and Sons, New York, 1906.

Ries, H.   The Clays of Florida; U. S. Geol. Survey 17th. Ann. Rept., Pt. III, p. 871, 1898.

Ries, H.   The Clays of the United States East of the Mississippi River; U. S. Geol. Survey, Professional Paper No. 11, 1903.

Ries, H. and Leighton, H.   History of the Clay Working Industry of the United States; John Wiley and Sons, New York, 1908.

Rowe, J. P.   Some Economic Geology of Montana; Univ. of Montana Bull. No. 50, 1908.

Searle, A. B.   Modern Brick Making; London, 1911.

Veatch, O.   Kaolins and Fire Clays of Central Georgia; U. S. Geol. Survey Bull. 315.   1907.

CHAPTER XI

PAVING MATERIALS
PAVING BRICK

History.—Paving brick are reported to have been in use in Holland for more than 100 years. They appear to have been in use in the northern part of England for more than half a century. They were first used in the United States in Charlestown, West Virginia, in 1870. In 1873 a block on the principal business street of the same city was paved with brick. This pavement was still in service after a lapse of more than 30 years. In 1875 a block of brick pavement was laid on a leading street of Bloomington, Illinois. The material was an inferior building brick, but it continued in service for more than 20 years.

Today brick is the only paving material employed in most of the smaller cities of the Mississippi Valley. It is used extensively in many of the larger cities of the same territory. The use of brick in all parts of the country for residence streets and light traffic business streets is rapidly increasing. There are in America approximately 200 plants devoted to the manufacture of paving brick. The output of an individual plant sometimes surpasses in a single year 100,000,000 bricks.

Definition.—A paving brick is simply a brick that will resist the crushing and abrading action of the traffic to which it is subjected. Such brick require a careful selection of the clay and a skillful manufacture.

The Clay.—Three distinct classes of clays are employed in the manufacture of paving brick: (1) Surface clays. (2) Impure fire clays. (3) Shales. While surface clays are extensively used in the manufacture of building brick they are ordinarily unsuitable for making paving brick. It is practically impossible to burn surface clays hard enough for paving brick without their losing their shape. Pure fire clay on account of its infusibility is not well adapted for making paving brick. Such brick are expensive to burn, lack density, hardness and strength. Impure fire clay makes a fair quality of paving brick. The process of manufacture is rather expensive. Such bricks vary in color from cream to buff and absorb from 2.5 to 7 per cent of water. Most paving bricks are now made from shale for this material makes a better and cheaper paving brick than either surface or fire clay.

Slate can not be rendered plastic by grinding and mixing with water. Shales may frequently be distinguished from fire clay by the conchoidal fracture of the former material. (See Figs. 281 and 282.)

Manufacture.—Soft homogeneous clays are run through rollers to crush the lumps, and from the crusher the material goes directly to the brick machine. It is usually desirable to run the material first through a pug mill, where it is mixed and worked

Fig. 281.—Scene in a shale pit showing the joint system and fracture of the shale, also the method of loading cars with shale. By courtesy of the National Paving Brick Manufacturers Association.

with water into a plastic mass. Hard clays and shales are often reduced in a dry pan to a fine powder. The dry pan consists of two heavy rollers or wheels which run in a revolving pan that has a perforated bottom. It is necessary that the clay should be reduced to an impalpable powder for four reasons: (1) The product fuses at a lower temperature. (2) The production is of an even and close-grained texture. (3) The resulting brick are tougher. (4) The brick are more impervious. The powdered and screened clay is tempered with water in the pug mill

or a wet pan which differs from the dry pan in that the bottom is water tight. The wet pan is said to give better results than the pug mill for the material can be retained in the pan until it is thoroughly tempered. This process, however, requires a large plant, much labor and power. (See Figs. 283, 284 and 285.)

Molding.—Most paving brick are made of what is known as the stiff-mud process. A few yards still use the old fashioned soft-mud and re-pressing system. Almost universally the mold-
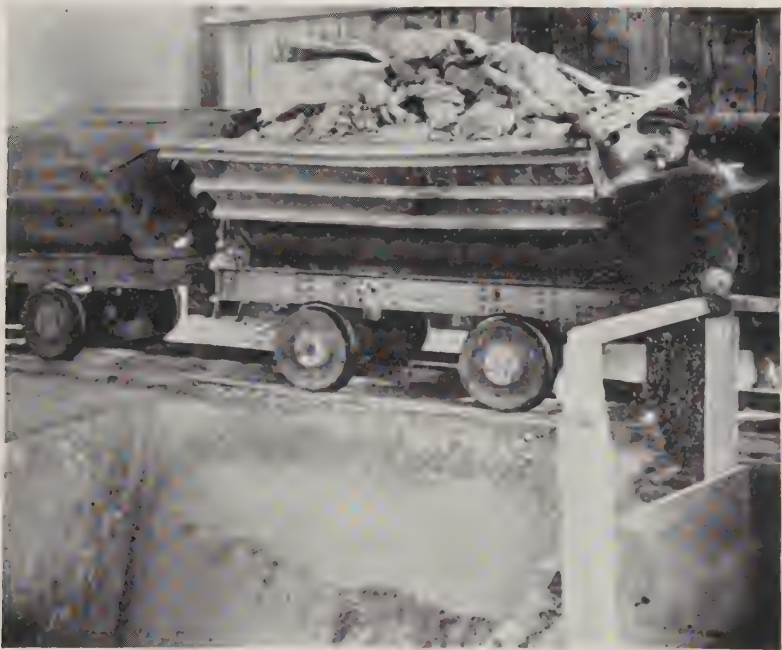
Fig. 282.—Car of shale, which has been loaded with a steam shovel, ready to be dumped into the crushing machine. Here the primary crusher receives a whole car load of shale at once. In this crusher the shale is broken into fragments not exceeding six inches in diameter. The shale then passes to a secondary crusher in which the shale is further reduced to fragments not exceeding three inches in diameter. The crushed shale passes from the secondary crusher into the dry pan. By courtesy of the National Paving Brick Manufacturers Association.

ing is done by an auger machine which forces the tempered clay or stiff mud through a die. This gives a continuous bar of compressed clay which passes under an automatic machine that cuts the bar into brick of uniform size. (See Fig. 286.)

Re-pressing.—After leaving the molding machine stiff-mud

brick are usually re-pressed. Re-pressed brick are more symmetrical in form and therefore make a smoother pavement. It is not certain that the breaking of the bond of clay in the process of re-pressing does not diminish the strength and decrease the durability of the brick. (See Fig. 287.)

Drying.—The molded or re-pressed brick are placed on cars or trucks and conveyed to the drying house. Here they should be thoroughly dried for drying facilitates the burning process. (See Figs. 288 and 289.)

Fig. 283.—Looking into a primary crusher. By courtesy of the National Paving Brick Manufacturers Association.

Burning.—Paving brick are usually burned in down-draft brick ovens with fire pockets or furnaces built in their outer walls. The bottoms of the kilns are perforated that the expelled gases may pass through the flues which are beneath the floors and which lead to the chimney. The fire passes up through the furnaces into the kilns and then down through the brick to be burned to the flues, and from thence to the chimney. The initial fire is low that the water may be expelled without cracking the brick. Even thoroughly dried brick contain from 20 to 30 per cent of water.

After the water smoking has ceased the fires are gradually increased until the temperature through the kiln is sufficient to vitrify the brick. Most shales vitrify at from 900 to 1,000 degrees C. while some impure clays require a temperature of 1,300 degrees C. for vitrification. The time required to raise the temperature of the entire kiln to the point of vitrifying varies from 7 to 10 days. (See Figs. 290, 291, 292 and 293.)

Size.—The size of paving brick is usually 2"x4"x8". Paving
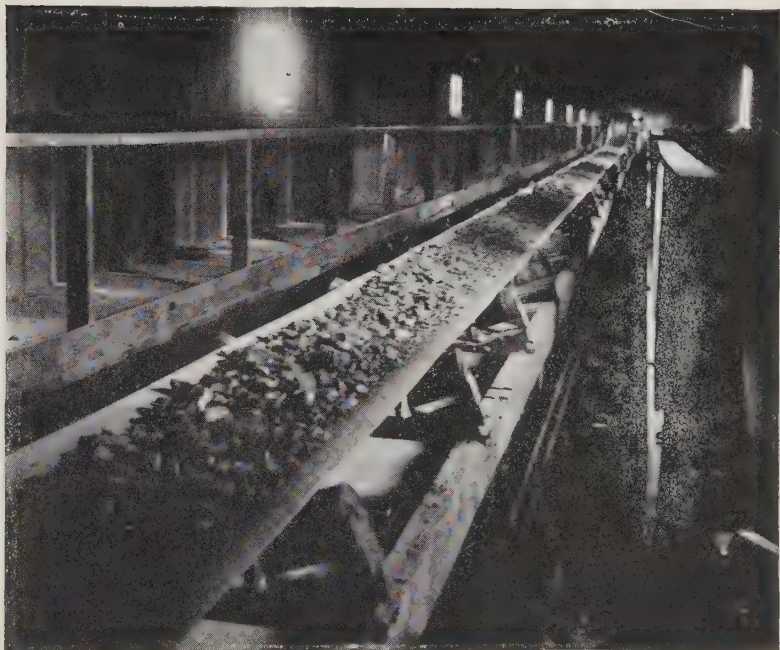
Fig 284.—Crushed shale passing on a belt conveyor from the secondary crusher to the dry pan. By courtesy of the National Paving Brick Manufacturers Association.

blocks are usually 3"x4"x9". Unfortunately there is a considerable variation in size in different parts of the country. (See Fig. 294.)

Form.—The usual form of brick is with flat sides and square corners. Three variations, however, are in somewhat common use (1) Rounded corners to prevent slipping. (2) Grooves on the sides and ends to increase the holding power of the material used to fill the joints between the brick. (3) Raised letters or

buttons on the sides to hold the bricks apart and to facilitate the introduction of the joint filler. (See Figs. 295, 296, 297, and 298.)

Figures 295, 296 and 297 show different forms of the grooves employed to facilitate the introduction of the joint filler and to increase its holding power. The first two are objectionable for the brick spalls off from the edge down to the groove, especially when the joints are filled with sand. Fig. 296 is better than 295 for the vertical grooves facilitate the introduction of the joint filler. It would be better to have the vertical grooves extend clear

Fig. 285.—Feeding a dry pan. By courtesy of the National Paving Brick Manufacturers Association.

across the face of the brick. Fig. 297 is a little less objectionable than any of the others. Fig. 298 represents either 295 or 296 cut in two pieces and the two halves placed side by side.

The name of the manufacturer often appears in sunken letters on the sides of the brick for two reasons: (1) The purpose of advertising. (2) To increase the holding power of the material used to fill the joints. The grooves and the sunken letters are all added in the process of re-pressing.

Requisites.—(1) Paving brick should be reasonably perfect

in shape. (2) They should be free from any marked warping or distortion. (3) They should be uniform in size so as to fit closely together and make a smooth pavement. (4) They should be hard so as to resist the crushing action of the wheels of vehicles. (5) They should be tough so as to resist the abrading action of traffic. (6) They should be homogeneous in texture. (7) They should be free from laminations or seams. (8) They should be of the same grade. The last three requisites are necessary that the brick may wear uniformly.
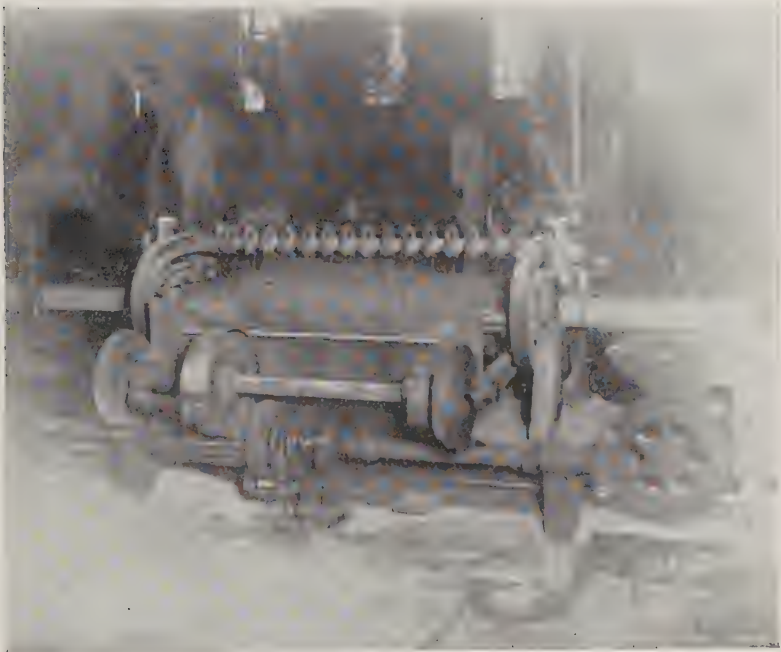
Fig. 286.—A cutting table cutting the stream which flows from the compressing machine into rectangular pieces the size of brick. By courtesy of the National Paving Brick Manufacturers Association.

Testing.—The testing of brick by well established methods is necessary for two reasons: (1) To determine whether the brick are suitable for paving purposes. (2) To enable comparisons to be made between different classes of brick.

Specific Gravity.—The density of paving brick depends largely upon the character of the original clay employed and the kind of fuel used in the burning of the brick. The specific gravity may be determined by weighing the brick in air. Then saturating the

brick with water and weighing in air a second time. Then weighing the brick in water. The formula in general use is:

Specific gravity $= \dfrac{Wa}{Ws-Wi}$

Crushing Strength.—There are three well known methods of testing the crushing strength, employing respectively (1) cubes, (2) half bricks, or (3) whole bricks, in the testing machine. Equal distribution of the pressure over the whole surface is

Fig. 287.—A series of repressing machines at work. By courtesy of the National Paving Brick Manufacturers Association.

insured by grinding the compressed surface accurately to planes, by the use of a thin coat of plaster of Paris, or by the insertion of layers of blotting paper, cardboard, etc. The brick may be tested on end, edgewise or flatwise.

Tests on cubes show that paving brick vary in their crushing strength from 10,000 to 20,000 pounds to the square inch. The load should be applied uniformly to the flattened surface by whatsoever method this surface may have been produced.

Transverse Strength.—This test is usually made by placing the

brick upon two knife-edges and applying a steady pressure on the upper side of the brick through a third knife-edge placed midway between the other two. The result, expressed in terms of the modulus of rupture, is computed by the following formula:

$$R = \frac{3\,W\,l}{2\,b\,d^2}$$

R represents the modulus of rupture in pounds per square inch, *W* the breaking load in pounds, *l* the distance between

Fig. 288.—Cars of brick at the discharged end of the dry pan. By courtesy of the National Paving Brick Manufacturers Association.

supports in inches, *b* the breadth of the brick in inches, and *d* the depth of the brick in inches. The modulus of rupture usually varies from 2,000 to 3,000 pounds.

Absorption.—The absorptive power of a brick is regarded as a measure of the porosity of the brick, or the degree of vitrification. When the tests are conducted according to the directions given in the Report of Paving Brick Commission of National Brick Manufacturers Association, pp. 62-63, (T. A. Randall & Co., Indianapolis, Ind.), shale paving brick usually show less than 2 per

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cent of absorption with some of the best brick ranging from 0.75 to 1.50 per cent. Tests showing less than 0.5 per cent of absorption indicates an over-burned and brittle brick. Good paving brick made of impure fire clay rarely absorb less than 2.5 per cent of moisture, and often over 5 per cent.

Impact and Abrasion.—This is the most crucial test of paving brick. It exceeds in importance all other tests combined. The results are jointly dependent upon four factors: (1) The tough-
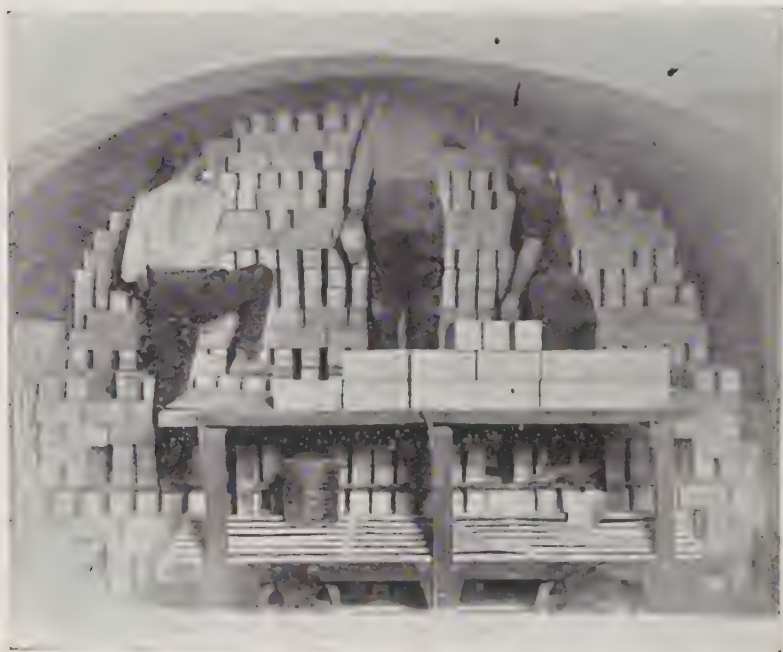
Fig. 289.—Setting the brick in the kiln after they have dried. By courtesy of the National Paving Brick Manufacturers Association.

ness of the brick. (2) Its ability to resist shock. (3) Its hardness. (4) Its power to resist abrasion.

The test is made by rolling or tumbling the brick, with or without fragments of iron, in a foundry rattler or cast iron barrel. There are many modification of the process.

Merits of Brick Pavements. Paving bricks have many attractive features: (1) They may be purchased in small units of practically uniform size. (2) They may be secured in large or small quantities. (3) They may be laid rapidly without expert labor. (4) When pipe lines are injured, demanding a disturbance

of the pavement, ordinary tools and intelligence can restore the original surface. (5) Brick pavements give a good foot hold for horses. (6) They do not wear slippery. (7) They are adapted to all grades. (8) They offer no tractive resistance when the joints are filled with Portland cement. (9) They are not noisy when properly laid. (10) They yield but little mud or dust. (11) They are easily cleaned. (12) They are only slightly absorbent when the joints are filled with sand, and non-absorbent
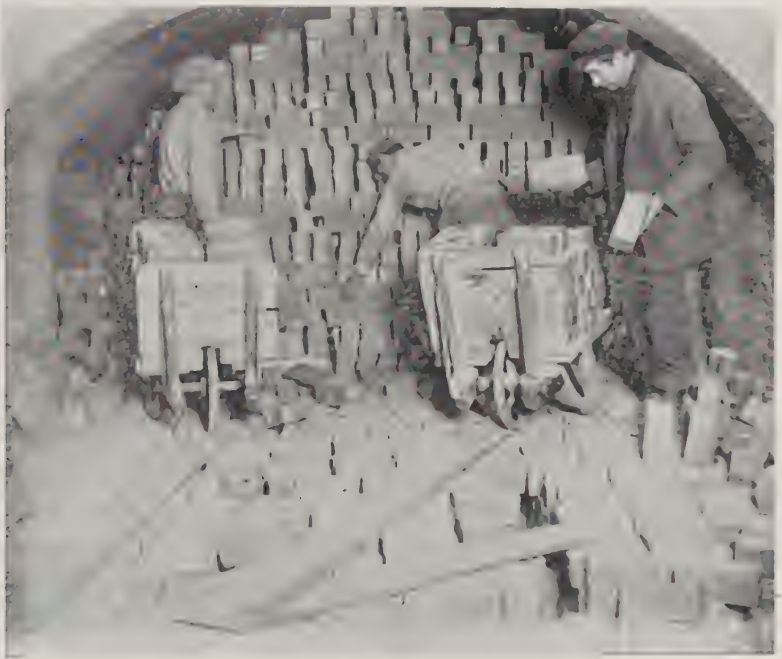
Fig. 290.—A scene showing how a section of the continuous kiln is being emptied of brick ready for market. By courtesy of the National Paving Brick Manufacturers Association.

when filled with tar or cement. (13) They are pleasing in appearance. (14) They are very durable when the joints are filled with Portland cement. (15) They are easily repaired. (See Fig. 299.)

Recently the monolithic style of construction has been introduced for brick pavements. Here the sand cushion has been entirely eliminated and the bricks are laid on the concrete foundation before the concrete is fully hardened.

Price of Brick for Pavements. The price of paving brick

Fig. 291.—This scene represents in the foreground an incoming train ready for loading and in the background a continuous kiln of more than one end compartment. By courtesy of the National Paving Brick Manufacturers Association.

varies largely with the locality. The freight rate is an important factor in determining cost. The price per thousand at the kiln is usually between $8.00 and $10.00.

STONE PAVEMENT

History.—Hornblendic rocks were used in paving the streets of Rome prior to the advent of the Christian Era. The roads of the Romans were constructed in fairly straight lines, with but little regard to topography or natural obstacles. The roads were

Fig. 292.—A modern rectangular kiln. By courtesy of the National Paving Brick Manufacturers Association.

costly in construction but permanent. The earliest dressed stone pavement in the United States was laid on Broadway, New York City, 1849. The material used was rectangular granite blocks.

Size of blocks.—Many of the blocks of stone now used for paving purposes are from 8 to 10 inches in length, 7 to 8 inches in width and from 3 to 4 inches in thickness. Some of the blocks of granite which are too small for monumental and constructional stone are now manufactured into paving stone. This material was formerly a waste product at the quarry but it now becomes an important by-product.

Granite. — Granite is more largely employed for paving

blocks than any other variety of stone.   Granites are generally
regarded as the hardest and most durable of stone paving blocks.
There are a few notable exceptions.   A granite abnormally high in

Fig. 293.—Removing the finished brick from a round down draft
kiln.   By courtesy of the National Paving Brick Manufacturers
Association.

its quartz content is too brittle for paving purposes.   A granite
containing too much of the feldspars is easily decomposed.   A
granite exceedingly rich in its mica content is too easily split for
use in paving blocks.   This condition holds especially true of

granite gneiss. Gneisses that result from the metamorphism of feldspathic sediments are too much stratified for paving blocks. When quartz fails, and the ferromagnesian mineral is hornblende, the resulting syenite makes one of the best of stone paving materials. As a rule the richer in hornblende the syenite is the better the paving stone will be.

The granitic rocks of the Appalachian belt, together with those

Fig. 294.—Manufactured brick coming out of the kiln on a gravity carrier. An inspector is standing next to the door rejecting the brick not going into the class of those being loaded into the car for shipment. By courtesy of the National Paving Brick Manufacturers Association.

of California, South Dakota and Wisconsin, are largely used in the manufacture of paving blocks.

Trap.—These dark colored, hard, compact and tough igneous rocks are not easily broken into standard sizes for paving blocks, because they lack the characteristic rift and grain of the granites. They are resistant and durable but expensive to work. For these reasons they are not widely used for paving blocks. They are abundant along the Connecticut River in New England and the

Hudson River in New York. They are extensive in New Jersey, in California and in Oregon.

Sandstone.—Sandstones are much used for paving purposes because (1) They are easily worked. (2) They are sufficiently abundant. (3) They are widely distributed. (4) They are
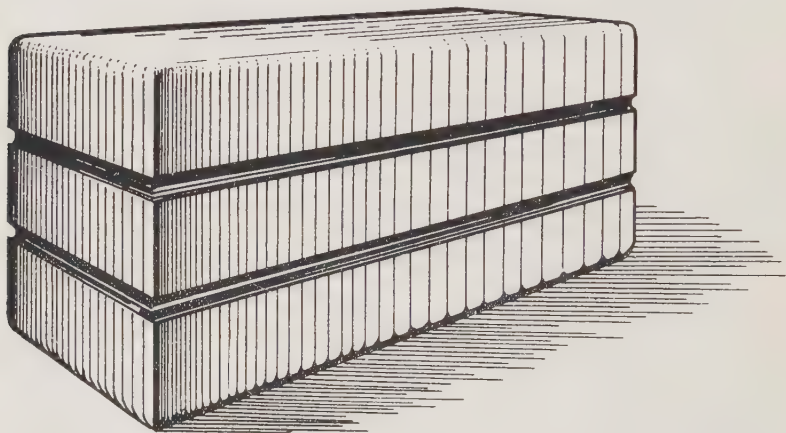
Fig. 295.—Grooved paving block. Drawing by L. W. Kesler.
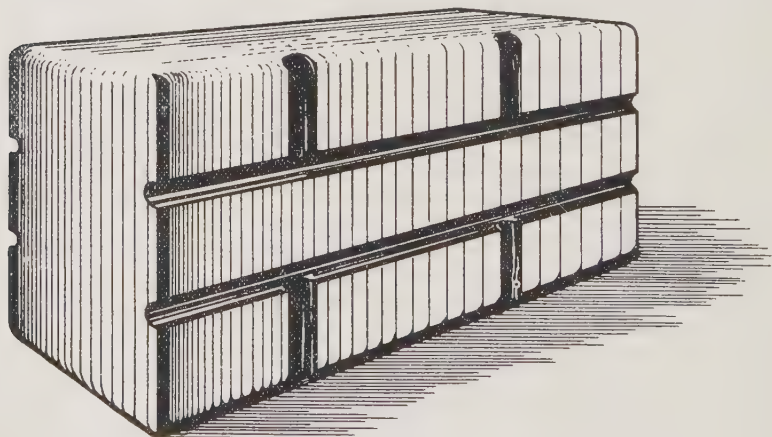
Fig. 296.—Grooved paving block. Drawing by L. W. Kesler.

resistant to abrasion. (5) They do not wear slippery like many granites.

The Potsdam sandstone of New York, which consists of quartz grains bound together with a cement of silica, has been extensively used for paving purposes. The same holds true, especially in

many cities bordering the Great Lakes, for the Medina sandstone of New York. The quartz grains of this sandstone are cemented together with the oxide of iron and a little calcium carbonate. The stone is durable. The sandstones of Boulder county, Colo-
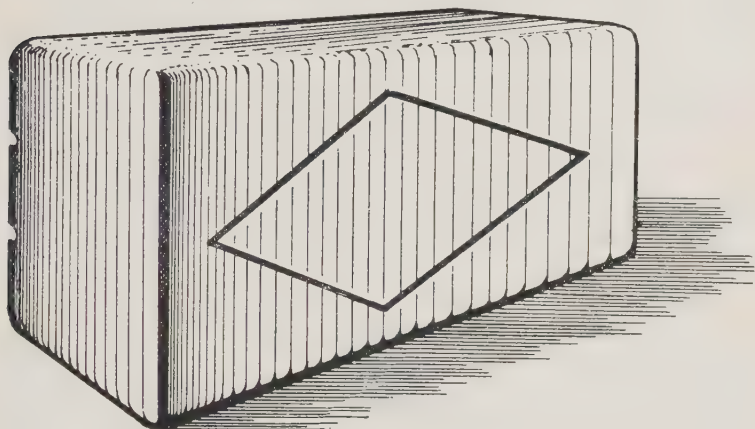
Fig. 297.—Grooved paving block. Drawing by L. W. Kesler.
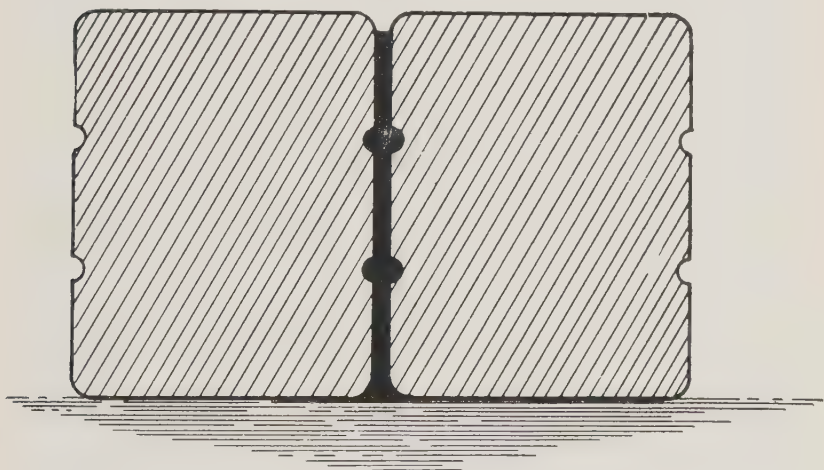
Fig. 298.—A grooved paving block cut in two pieces and the two halves placed side by side. Drawing by C. H. Richardson.

rado, are hard and tough. They wear well in a pavement. Although in time they wear to a smooth surface they do not become slippery. The Kettle River sandstone which is fine grained and quarried extensively at Sandstone, Minnesota, wears

flat and is largely used for paving purposes in Minnesota and Wisconsin. The Sioux Falls quartzite of Sioux Falls, South Dakota, consists almost wholly of silica. There is just enough
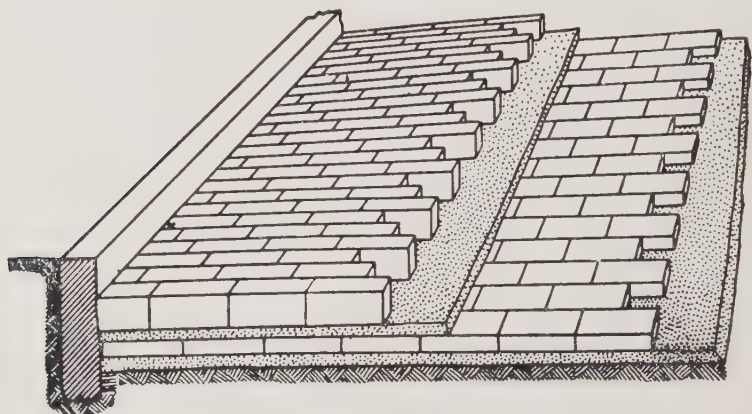
Fig. 299.—Section of a brick pavement with brick foundation. By courtesy of I. O. Baker.
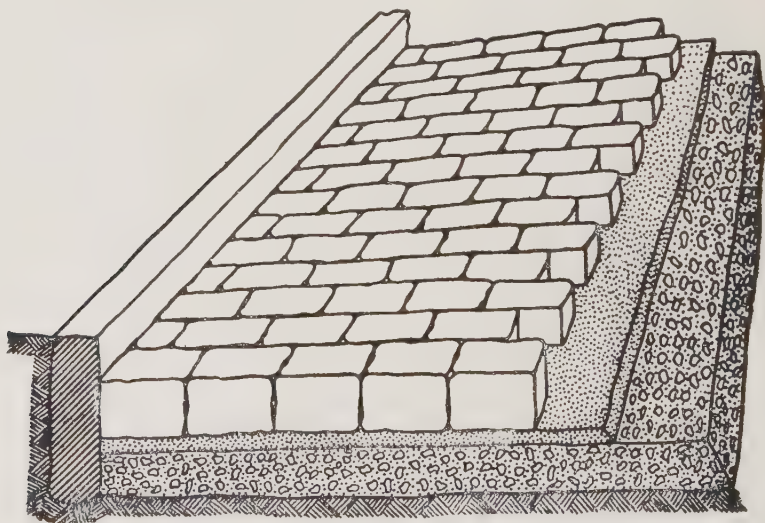
Fig. 300.—Section of stone-block pavement. By courtesy of I. O. Baker.

of the oxide of iron present to impart a reddish color to the stone. It is one of the most resistant to abrasion of all paving stone, yet it wears smooth with a somewhat glassy surface.

Limestone.—Some varieties of limestone are fairly dense and strong. Such varieties are often used for paving purposes. They wear unevenly. They are easily broken by heavy traffic and split by frost. Limestones are widely distributed and usually they are easily worked into paving blocks. (See Fig. 300.)

ROAD BUILDING ROCKS

Requisites.—(1) A suitable road stone should be soft enough to grind to dust slowly under the traffic to which it is subjected. (2) The dust should have a high cementing power. (3) The

Fig. 301.—Limestone quarry, Prospect, Oneida County, New York. Photo. by M. C. Collister.

separate fragments of the stone should have sufficient strength to resist the crushing action of the wheels. Where the traffic is light a hard stone may not furnish enough dust to replace that blown away by the wind, washed away by the water, and to bind the surface. In such a case a softer stone, or one with a higher cementing power is preferable.

Trap.—This is a popular term applied to any dark colored, massive, igneous rock. Trap is a very compact and elastic rock. It has a high resistance to crushing without being too brittle. Its

dust has the cementing power in a high degree. The different traps are not uniformly desirable for purposes of road construction but nearly all of them are better than the best of other rocks. The basic, igneous rocks, called traps, should be placed first in the order of utility amongst all road building stone.

Granite.—Next in value to the trappean rocks as road metal are those commonly called granites. An essential feature of granite is an evenly granular structure coarse enough to be distinctly visible to the naked eye. They vary somewhat in value, but as a rule they are considered inferior road metal for three reasons. (1) Their coarsely granular texture. (2) The brittleness of both the requisite quartz and feldspars. The low cementing power of its dust. If the quartz fails so that the rock may be technically called a syenite it is the best for road metal amongst the various types of holocrystalline rocks. The gneissoid granites make a very inferior road material.

Felsite.—This hard flinty rock has about the same composition as a granite. To the unaided eye it appears homogeneous. It is sometimes classified amongst road metals as a granite. It is particularly high in its cementing power.

Limestone.—Limestones are usually deficient in hardness and toughness for road metal. They possess cementing power in a fair degree. The best limestones for road metal require three factors: (1) The layers of the limestone should be comparatively thin. (2) There should be little sign of crystallization. (3) They should contain less than 25 per cent of clayey matter. (See Figs. 301 and 302.)

In proportion as limestone assumes the crystalline character of marble its value as a road metal diminishes, for its crystalline structure in most cases so far weakens the mass that it is apt readily to pass into the state of powder. Marbles have a high per cent of wear and a low cementing power according to the reports compiled by the Massachusetts Highway Commission 1896-1901.

Sandstone.—Sandstones are deficient as road metal for two reasons: (1) They are easily reduced to sand. (2) They are deficient in binding power. They are, however, highly resistant to abrasion and impact. In some instances sandstones have sufficient binding material between the individual grains to hold the mass firmly together in such a manner as to render them fair road building materials.

Chert, which is the variety of quartz that breaks with a splintery fracture rather than conchoidal, will usually give fairly good results as a road metal. It is of great value when it occurs

in those portions of the country where good road building materials are scarce or entirely wanting.

Shale.—For engineering purposes when the indurated clay is nearly pure it is termed an argillaceous or clay shale. When it contains a considerable amount of sand it is termed an arenaceous

Fig. 302.—Stone crushing plant, Prospect, Oneida County, New York. Photo. by M. C. Collister.

or sandy shale. For road building the argillaceous shales are worthless and the arenaceous shales are useful only for a top dressing. They are not satisfactory even for that purpose.

Slate.—As a road metal the fragments of slate quickly grind to a dust which has but little binding power. Slate makes a smooth road, but one that wears away rapidly when wet. It is sometimes used as a surfacing or binding material, but it is much inferior to clean sand or good stone dust.

Field Stones.—In many glaciated districts an excellent road material may be obtained by crushing the various boulders and pebbles that are too coarse for use in gravel roads. In northern New England the complex mixture of the basic and acidic intrusives with the metamorphosed sedimentaries has produced a very satisfactory permanent road. Whenever glacial boulders are badly decomposed they are essentially unfit for road building. (See Fig. 303.)

Fig. 303.—Sand and gravel deposit in Northern Vermont, used in making permanent roads.   Photo. by C. H. Richardson.

For further information concerning the road building rocks of the United States the student is referred to the Preliminary Report on the Geology of the Common Roads of the United States, by N. S. Shaler, U. S. Geological Survey, Fifteenth Annual Report, 1893-1894, pp. 255-206.

For references to standard works bearing in part on paving brick see list of references at the close of chapter X.

CHAPTER XII

CEMENT AND CONCRETE
CEMENT

History.—The extensive use of concrete in recent years has led many to speak of the cement industry as a new industry, and the present as the Age of Concrete. Hydraulic cement has been used in some form since the dawn of civilization. The Egyptians more than 4,000 years ago manufactured natural cement. 500 years before the beginning of the Christian Era an aqueduct some 70 miles in length was constructed of natural cement to supply the city of Carthage with water. The ancient Greeks and Romans used hydraulic cement in the foundations of many buildings, in superstructures, water mains, sewers and roads. The dome of the Parthenon, erected at the beginning of the Christian Era, is an example of the use of concrete construction by the ancients.

The art of manufacturing hydraulic cement appears to have been lost during the Middle Ages. In 1756 it was rediscovered by John Smeaton, who burned argillaceous limestones to manufacture a lime that would set under water. This material was used in the construction of the Eddystone lighthouse.

In 1796 Joseph Parker manufactured natural cement, which he styled Roman cement, by crushing and burning septaria nodules from the Isle of Sheppey, off the coast of England. In 1802 at Boulogne, France, natural cement was manufactured from septaria pebbles which were called Boulogne pebbles. In the interim from 1813 to 1818, M. Vicat manufactured hydraulic cement by mixing chalks and clays. In 1818 Canvass White produced natural cement from the hydraulic limestone deposits near Fayetteville, N. Y. Since that date hydraulic cement has been extensively manufactured in the United States.

In 1824 Joseph Aspdin manufactured Portland cement by calcining lime and clay. He styled the product Portland cement because the finished product closely resembled the famous oolitic limestone from the Island of Portland, Derbyshire, England. The limestone, like the oolitic limestone of Bedford, Indiana, has been used extensively for constructional purposes. In 1825 Aspdin established a plant at Wakefield, England, for the manufacture of Portland cement. In 1875 the first American Portland

cement was manufactured by David O. Saylor, Coplay, Pa. For the next 15 years the development of the industry in the United States was very slow but since the year 1890 the output has assumed large proportions. In 1915 the output for the United States was 85,732,000 barrels.

Quick Lime.—Quick lime, or common lime, is manufactured by burning pure, or somewhat impure limestone, in kilns and sometimes grinding the burned product to an impalpable powder. In the process of burning the limestone the carbon dioxide is driven off and lime, CaO, remains in the kiln. If the limestone

Fig. 304.—Niagara limestone, Lauer and May limekiln quarry, east of Brighton, New York, looking north 15° east. Near top of Lockport. Photo. by H. L. Fairchild.

contains more than 12 per cent of impurities it possesses the property of absorbing water with great avidity. This absorption is accompanied by heat and the evolution of caustic vapors, and finally the resulting product is a powder. The product is slaked lime and the process is known as slaking. (See Fig. 304.)

Good lime hardens in the air. It comes in hard lumps. In the process of slaking it increases in bulk from $2\frac{1}{2}$ to $3\frac{1}{2}$ times. It will also absorb $\frac{1}{4}$ its own weight of water. When too much water is added in the process of slaking the lime, it forms a sort of paste. Lime mortar is made by mixing slaked lime with

sand. This product is used extensively for building purposes. If not enough water is added in the slaking of the lime, and more water is then added, it renders the lime granular and lumpy.

Lime Mortar.—Lime mortar is manufactured by mixing a paste of slaked lime with $2\frac{1}{2}$ to 3 volumes of clean sand. The sand reduces the cost of construction and prevents the mortar from cracking. If too much sand is used the mortar will be porous. Two processes are involved in the hardening of the mortar. (1) The formation of crystals as the lime gradually dries out. (2) The formation of calcium carbonate or limestone through the absorption of carbonic acid from the atmosphere. It is obvious that lime mortar cannot harden under water or in the soil for crystallization can occur only on the drying out of the lime. The length of time required for lime mortar in a thick wall to crystallize is well illustrated by the Scotch proverb, "When a hundred years are past and gane, then gude mortar turns into stane."

Hydraulic Lime.—Hydraulic lime is manufactured by burning a limestone which contains 10 per cent or more of silica and a sufficient amount of alumina to enable the burned product to set under water. There is usually from 15 to 25 per cent of the silica and alumina combined. The burned product consists of free slaked lime together with the silicates and aluminates of calcium.

The free lime slakes readily in water but the process is retarded by the presence of the silicates and aluminates. If hydraulic lime is mixed with water to form a paste it can be used in the same manner as quick lime. The material dries, hardens and slowly absorbs carbon dioxide from the atmosphere. If used without sand it swells and cracks. When used under water hydraulic lime sets with more or less rapidity. The larger the percentage of common lime present the slower will be the setting, for quick lime is inert under water and in damp soil. The setting is due to the presence of the combined lime which suffers crystallization in the same manner as in hydraulic cement.

Natural Cement.—American natural cement was first called Rosendale cement because it was first manufactured at Rosendale, N. Y. Its manufacture consists of burning hydraulic limestone in plain upright kilns with heat insufficient to cause vitrification, and subsequently grinding the product to a fine powder. The unground product will not slake with water. When the fine powder is mixed with water it hardens or sets rapidly both in air and in water. During the process of burning the carbon

25

dioxide of the limestone is driven off and the lime combines with the silicates, aluminates and ferrites of calcium. If the limestone the silcates, aluminates and ferrites of calcium. If the limestone is dolomitic, magnesium compounds will result. According to Prof. Robert Fletcher, Director of the Thayer School of Civil Engineering at Dartmouth College, Hanover, N. H., the presence of magnesium carbonate up to 3.5 per cent is not injurious to the cement. Some good cements have been manufactured from limestone containing between 3.5 and 5 per cent of magnesium but above that upper limit all limestones should be rejected for cement purposes.

Hydraulic limestone is usually stratified and the different layers vary somewhat in their chemical composition. Unless chemical analyses prove the stone from a given quarry to be fairly constant in composition the quarried blocks are mixed so that any error from too much silica, alumina or magnesia in any given layer may be corrected in the finished product.

The rock is generally quarried by the open cut method where the stripping is light. It is sometimes mined, rather than quarried, by tunnels and chambers. The quarried limestone is broken into fragments convenient for feeding into an ordinary rock crusher, which breaks it into fragments that vary in size up to 6 inches, and then conveyed by an ordinary tramway to the loading platform at the top of the kiln.

In the process of burning there is an average loss of about 25 per cent of the material from the burnt and over burnt product. The sorted calcined rock is conveyed to rotary crushing machines where it is reduced to the form of a powder, screened and the coarser particles reground. The whole product is conveyed from the reducing mills to mixers where the entire product is uniformly mixed and then conveyed by chutes to the bags and barrels in which it is packed for storage and shipment.

Portland Cement.—The term Portland cement is used to designate the artificial product formed by burning a mixture of limestone and clay in correct proportions to the point of incipient fusion. Portland cement differs from natural cement both in character of the raw material used and in the quantity of heat required in its manufacture. (See Fig. 305.)

There are 5 steps involved in the process of manufacturing the cement: (1) The quarrying of the limestone and cement rock. (2) The grinding of the raw materials. (3) Proportioning and mixing. (4) Burning the mixture. (5) Grinding of the clinker.

1. The cement rock and limestone are quarried by the open

Fig. 30.— Plant of Pacific Portland Cement Company, Consolidated, Cement, Solano County, California. By courtesy of the California State Mining Bureau.

cut method or mined by means of tunnels and chambers. Cement rock and limestone are the materials most commonly used in the manufacture of Portland cement. Other materials sometimes used are limestone and clay, marl and clay, chalk and clay. The raw materials should contain from 21 to 24 per cent of silica; 6 to 8 per cent of alumina; 2 to 4 per cent of iron oxide; 60 to 65 per cent of calcium carbonate. The per cent of magnesia, sulphuric acid and water should be small.

2. In the grinding of the raw materials two processes have been extensively used. One is known as the wet process and the other as the semi-wet process. The former is better for soft or wet materials as marl and clay, or chalk and clay. The materials are mixed in a vat or wash mill with a large excess of water. The lumps are reduced by agitators to a finely divided state so that the material may be held in suspension in the excess of water. The sediment is drawn off into settling tanks and molded into bricks which are dried and calcined in either stationary or rotary kilns.

3. In the semi-wet process the marl or chalk is disintegrated and run into storage basins. The clay is dried, pulverized and mixed with the proper amount of marl in pans. Enough water is added to this mixture to produce a thick creamy mass. The mixture is then ground and run into tanks where it is constantly stirred by means of pedals or compressed air. The wet slurry is pumped into rotary kilns where it is burned at high temperatures.

4. Rotary kilns are used exclusively in the United States at the present time in the manufacture of Portland cement. In the kiln the material is burned to a clinker. The clinkers should appear in the form of balls ranging in size from sand grains up to one inch in diameter.

5. The clinker emerges from the kiln at a temperature of red heat. It is cooled by water. When thoroughly cooled it is ground to a powder so fine that 90 per cent of the product will pass through a 100 mesh sieve. The product is then seasoned, weighed out into bags and barrels for storage or shipment.

In the dry process as used for cement rock and limestone the quarried product is crushed, mixed, dried, ground, calcined and the clinker ground to a powder.

The Hudson and Catskill plants use the dry method entirely. Limestone, clay and coal (fuel) are each ground separately; the two former are mixed and fed into the upper end of a rotary kiln, while the coal is blown in from the lower end of the kiln. The clinker secured by this dry method ranges in size up to that

of a man's head. The clinker is cooled by being carried back and forth on an endless steel conveyor and finally dumped into a crusher, from which it goes to the fourth set of grinders. Water is not used at any time in this process.

White Portland Cement.—White cement is manufactured from pure white sand, white quartz, white limestone, or ground marble. Although this white cement or white artificial stone is about 4 times as expensive as ordinary Portland cement it is extensively used in the United States.

Lewis and Chandler in their "Popular Handbook for Cement and Concrete Users" give the following summary of uses for white cement:

1. Building ornamentation. For exteriors, steps, railings, columns, doorways, windows, casings, cornices, panels.
2. Stucco.
3. Concrete building blocks.
4. Interior decoration. Staircases, wainscoting, panels, reliefs, floors.
5. Statuary. An improved substitute for plaster in reproducing statuary figures and groups for galleries of casts, or exterior and interior decoration.
6. Cemetery work. For monuments, vaults, columns, urns, etc.
7. Parks and grounds. For fountains, seats, railings, walks, bridges, etc.
8. Tile, mosaics, etc. In the production of white or delicate tints and as a cement in the place of Keene's cement.
9. Colored concrete. Permits the use of bright or delicate colors.
10. Painting iron or concrete.
11. Stainless mortar. For laying up Bedford limestone, sandstone or marble.
12. Setting and pointing between blocks or slabs of white marble, limestone, or brick.

Pozzuolana.—Pozzuolana is often called slag cement. It is sometimes classified as Portland cement by the manufacturers. It differs materially from Portland cement. It is an excellent cement for many purposes but it possesses qualities that make it objectionable as a substitute for Portland cement in many classes of work. The cement will set either under water or in the open air. The product derived its name from the Italian city Pozzuoli which is situated near the foot of Mount Vesuvius where the properties of cement produced by volcanic action were first discovered.

In the manufacture of Pozzuolana blast furnace slags are used. The slag as it comes from the furnace is shorted by water under high pressure. In the rapid chilling of the slag about one-third of its sulphur is liberated, while the slag undergoes other chemical changes. The granulated slag is mixed with quick lime and ground to a powder sufficiently fine for 95 per cent of the product to pass through a 200 mesh sieve. The slag is dried before grinding. The lime is obtained from a very pure limestone. Caustic soda is added in small quantities to the water used in slaking the lime to render the cement quick setting.

Properties of Cement.—According to H. A. Reid the desirable properties in cement are: (1) That when treated in the proposed manner it shall at the end of a definite period develop a certain strength. (2) That it shall contain no compounds which may at any future time cause it to change its form or volume, or lose any of its strength. (3) That it shall withstand the action of any outside agency which may tend to decrease its strength or impair its durability.

Color.—Variations in color indicate different types of rock used in the manufacture of the cement or different temperatures during the process of burning.

Portland cement is usually a dull gray. Bluish gray indicates an excess of lime. Brown an excess of clay. Dark green an excess of iron. Yellowish tints signify over burning.

Natural cement ranges in color from a light yellow through dark gray to a chocolate brown.

Slag cement ranges from bluish white to lilac in color. There is sometimes in slag cement a bluish green tint due to the presence of calcium sulphide. Good slag cements do not stain blocks of white marble or creamy white sandstones and therefore they are often used in architecture.

Specific Gravity.—The specific gravity of good Portland cement ranges from 3.10 to 3.25. Natural cement varies from 2.75 to 3.05. Slag cement 2.6 to 2.9. A higher specific gravity than those given indicates an overburning of the material which is a source of weakness. A lower specific gravity may indicate an under burning of the product or the presence of adulterants. Plaster of Paris is often used as a legitimate adulterant. It serves as a retarder in the setting of the cement. The materials of lower specific gravity than Portland cement which are sometimes used in its adulteration are natural cement, slag cement, unburned limestone and cinders. The age of the cement, the fineness to which it is ground and its chemical composition may be responsible for a low specific gravity.

Acitivity.—This is the time required for a cement to set or harden. It may harden so quickly that the material is worthless for architectural purposes. It may set so slowly that it retards work and increases expense. The initial set takes place when the material begins to harden. The hard set occurs when the mass can not be appreciably distorted without rupture. The best cements acquire their initial set slowly and then harden rapidly.

Soundness.—A good cement will not expand, contract or check after the initial set has begun. Unsoundness in cement is often due to an excess of either free or loosely combined lime. The presence of the excess of lime may be due to any one or more of several factors. (1) To incorrect proportioning. (2) To insufficient grinding of the raw materials. (3) To under burning the products in the kiln. (4) To insufficient grinding of the calcined rock. (5) To lack of seasoning the finished product. Fresh cements made of good material will sometimes test unsound, while the unsoundness will disappear in a few weeks time.

Expansion and disintegration may be caused by an excess of magnesia, or by alkalies, or the presence of sulphides. Contraction may be caused by an excess of clay. In slag cements the unsoundness is generally due to the presence of quicklime, an excess of magnesia, or the presence of sulphides.

Fineness.—The finer a cement is ground the better will be its quality and the greater will be its covering capacity. For Portland cement 92 per cent of its weight should pass through a 100 mesh sieve. For natural cement 90 per cent. For slag cement 97 per cent of its weight should pass through a 100 mesh sieve.

Tensile Strength.—The tensile strength of cement is easily determined and is generally considered a true measure of the compressive, transverse, adhesive and searing values.

H. A. Reid in his "Concrete and Reinforced Concrete Construction" gives the tensile strength for Portland cement 28 days of age (1 day in moist air and 27 days in water) as 600 lb. Natural cement of the same age and under the same conditions as 225 lb. Slag cement under the same conditions as 500 lb.

Compressive Strength.—The Watertown Arsenal Report of 1902 gives the compressive strength of Portland cement gauged with 25 per cent water at the age of 1 day in air as 430 lb. per square inch. At 28 days of age in air as 3,130 lb. at 28 days of age, 1 in air and 27 in water as 7,580 lb.

Chemical Composition.—The chemical composition is one of the most important guides to the quality of the product. The

chemist usually grinds the cement to a very fine powder before determining any constituent that may be present. It is advised by some engineers that the true nature of the cement is best determined without pulverizing the material or otherwise changing its physical characteristics. In this manner the free silica which is always inert is separated from the mixture and determined separately. The combined silica is an active agent in the setting of the cement.

The average chemical composition of 11 well known American cements is given for reference.

$$
\begin{array}{ll}
\text{Silica, } SiO_2 \dots & 21.90\% \\
\text{Alumina, } Al_2O_3 \dots & 7.89 \\
\text{Ferric oxide, } Fe_2O_3 \dots & 3.09 \\
\text{Lime, CaO} \dots & 62.04 \\
\text{Magnesia, MgO} \dots & 2.33 \\
\end{array}
$$

$$98.74$$

The following shows the average composition of 7 high class American cements with the soluble silica separated in the analysis from the insoluble silica.

$$
\begin{array}{ll}
\text{Silica, } SiO_2 \text{ (Soluble)} \dots & 18.45 \\
\text{Silica, } SiO_2 \text{ (Insoluble in 10 per cent} \\
\quad \text{HCl)} \dots & 4.38 \\
\text{Alumina and iron oxides, } Al_2O_3 \dots & 9.46 \\
\text{Lime, CaO} \dots & 61.89 \\
\text{Magnesia, MgO} \dots & 1.78 \\
\text{Sulphuric oxide, } SO_3 \dots & 1.87 \\
\end{array}
$$

$$97.83$$

CONCRETE

Advantages of Concrete.—The advantage of concrete for a pavement foundation are: (1) It gives a smooth uniform surface upon which to lay the pavement. (2) It prevents the surface water from percolating to the subgrade. (3) By its thickness and resistance to flexure, it distributes the concentrated load over a considerable area of the subgrade. (4) Concrete acts as a bridge to support the pavement in case of a settling of the subgrade. (5) Being impervious to water and a nonconductor of heat, concrete protects water and gas pipes from freezing.

Theory of Concrete.—The proportions of the concrete should be so adjusted that the voids in the sand will be filled with cement paste, and the voids in the gravel or broken stone will be filled with cement mortar. The cement is the most expensive con-

stituent. If more cement or mortar is used than is required to fill all the voids, the cost is needlessly great. The cement is usually the weakest constituent. If more cement is used than is necessary the strength of the concrete is correspondingly decreased. In a perfect concrete every grain of sand will be coated with cement paste, and every point of each fragment of broken stone will be covered with cement mortar.

Gravel vs. Broken-Stone Concrete.—At the same price per unit of volume broken stone is the better for the following reasons: (1) The cement adheres more closely to the rough surfaces of the angular fragments of the broken stone than to the smooth surface of the rounded pebbles. (2) The resistance of concrete to crushing is due in part to the frictional resistance of one piece of aggregate to moving on another. Therefore broken stone makes a stronger concrete than gravel.

Portland Cement vs. Natural Cement.—Formerly natural cement was a trifle the cheaper per unit of strength. With the present prices Portland cement is a little the cheaper.

Wet vs. Dry Concrete.—Dry mixtures of neat cement, and also of cement and sand, are stronger than wet mixtures, provided the amount of water is sufficient for the crystallization of the cement. It is also true that in even a dry mortar or concrete, the amount of water is considerably in excess of that necessary for the crystallization of the cement, and this excess increases with the amount of sand and aggregate. An excess of water is an element of weakness.

ARTIFICIAL STONE

Several kinds of artificial stone are now in use for architectural and artistic purposes, and for the pavements of cellars, for footpaths, areas, and other localities not subjected to the tread of heavy animals and vehicles. They represent a combination of hydraulic cement, sand, pebbles, crushed stone, etc. Some of them possess considerable merit and are of value in localities where durable and cheap building stone is not supplied by nature.

The strength and hardness of all varieties of artificial stone vary directly with the ultimate strength and hardness attainable by the hydraulic ingredients employed. The quality of such stone as a unit may be improved by the employment of only the highest grades of cement.

Beton-Coignet.—This stone as invented by Coignet of Paris consists of Portland cement, hydraulic lime and clean sand, mixed together with a little fresh water. The peculiarities of the stone result from (1) The small quantities of water used in its manufacture. (2) A judicious choice of the qualities and proportions of the ingredients. (3) The thoroughness with which the mixing is done. The stone is nothing more than hydraulic concrete from which the coarse fragments have been omitted. It is used in France to a considerable extent in the construction of the walls of houses and in repairing masonry.

The so called Beton-Coignet stone of America consists of a mixture of either natural or Portland cement and sand that has been mixed, molded and compacted together for constructional purposes.

Portland Stone.—This stone is a mixture of Portland cement and sand, or sand and gravel compacted into form by tamping. Its strength and hardness is dependent upon the grade of cement employed. One part of dry cement is usually mixed with two or two and one-half parts of sand. To insure the production of a homogeneous stone the manipulation must be prolonged and thorough. It is used for flagging, for grindstones in England and for footpaths, etc.

the fact that the oxychloride of magnesium possesses hydraulic

Sorel Stone.—The composition of this stone is based upon

energy in a marked degree. The stone is manufactured by adding a solution of the chloride of magnesium of the proper strength and in the proper proportion to the oxide of magnesium. The strength of this stone, as well as its hardness, exceeds that of any other artificial stone yet manufactured. The stone can be manufactured cheaply for foundations and plain massive walls by incorporating in its body large pebbles and cobble stones.

McMurtrie Stone.—This stone consists essentially of the Portland stone in the interstices of which are formed compounds of alumina with the fatty acids by the double decomposition of alum and a potash soap. The advantages of the stone are: (1) Its low power of absorption. (2) The new products formed are insoluble in water. (3) They are not affected by the carbonic acid of the atmosphere. (4) They add considerably to the early strength of the stone. (5) They add also to the ultimate strength of the stone.

The water-absorbing capacity of this stone is about twice that of granite. Portland cement absorbs from 10 to 20 per cent of water. Mortar absorbs from 50 to 60 per cent of its own weight of moisture. This absorbed moisture tends to dissolve the soluble salts of lime, magnesia, soda and potash which upon evaporation leave a white efflorescence on the surface.

This stone has been used in the fronts of stores and dwellings and in the window trimmings of the National Museum.

Frear Stone.—This stone is made of good Portland cement, siliceous sand and gum shellac. The inventor of the stone used one part of cement with two and one-half parts of sand moistened with an alkaline solution of shellac of sufficient strength to furnish an ounce of the shellac to a cubic foot of the stone. The shellac is added to give an early strength to the stone. It is not certain that the shellac increases the ultimate strength of the stone, nor is it certain that the shellac will not decay and prove an element of weakness. It has been used to a considerable extent for architectural purposes in the West. It is not entirely satisfactory.

Ransome Stone.—This stone consists of sand and the silicate of soda. One bushel of sand is mixed with one gallon of the silicate of soda and either rammed into molds or rolled into slabs. At this stage in the process the blocks or slabs may be easily cut into any desired form. They are then immersed under pressure in a hot solution of the chloride of lime until they become saturated with this product. They are then drenched with cold water to wash out the chloride of sodium formed during the operation.

The stone is used for grindstones in England and for footpaths, etc.

Artificial Marble.—Gypsum and clay are made into a paste with gums or resins so that the surface of the product may be highly polished. To prevent the paste from setting too quickly a little sodium silicate, Na_4SiO_4, is added. The veins are made by either spreading colors, or threads of silk dipped in the desired

Fig. 306.—Type of building as built for the city of New York by the Board of Water Supply. H. L. Rogers, architect. Catskill aqueduct, portion of the new water system for city of New York. This brick building is trimmed with Onondaga litholite. Photo. furnished by the Onondaga Litholite Company, Syracuse, New York.

color, on a smooth non-absorbing surface and pouring the mixture on the colors or threads. The product is then remolded and polished. Pillars and columns are colored by wrapping in oil cloth, oil paper, canvas, etc., and then removing and polishing the product.

CUT CAST STONE

Cut Cast Stone is manufactured from any high grade natural stone, preferably a granite or hard marble. It is crushed, screened and graded to six different sizes—the largest being that which will pass a three-quarter inch screen. A very small proportion of the dust is used.

Fig. 307.—New York State Seal, 7 feet and 6 inches by 7 feet, as manufactured by the Onondaga Litholite Company for the new armory building at Ithaca, New York. L. H. Pilcher, State Architect. By courtesy of the Onondaga Litholite Company.

The different sizes of the crushed stone are weighed carefully into the mixer; the Portland cement and water also being carefully weighed, thus insuring a uniform product.

After mixing, the material is poured into either a sand, wood or plaster mold; a portable mixer, with which the liquid concrete

Fig. 308.—First Baptist Church, Syracuse, New York, built of terra cotta. Gordon Wright, architect. Photo. by Smith and Holmes.

is kept constantly agitated, being used to convey the material from the mixer to the molds. An electric crane is used for this purpose. This portable mixer handles two yards of material at one time.

After removing from the molds, it is carefully protected from changes in temperature and draughts for five days longer, after which all surfaces are carefully recut by machinery or by stone cutters. At least one-quarter of an inch of surface material is

Fig. 309.—Atlantic terra cotta, manufactured at Perth Amboy, New Jersey. By courtesy of the Atlantic Terra Cotta Company.

removed. Any texture and finish, which may be desired and which is obtainable in natural stone, can be secured in this product.

In addition to this, various colors and combinations are possible by combining different colored stones in the mix and using mineral colors to get the desired effect. A jet black slag, secured from the copper refineries, can be used to produce a stone with strong contrast like some of our natural granites.
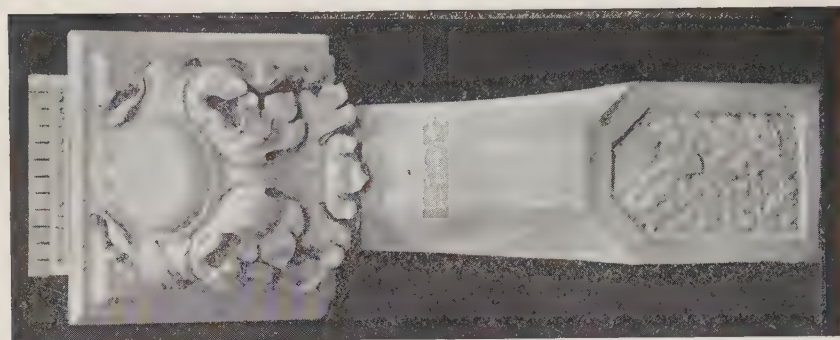
Fig. 310.
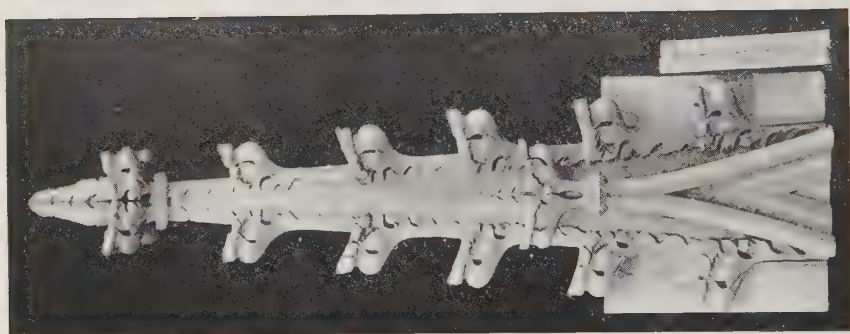
Fig. 311.

Fig. 312.

Atlantic terra cotta. By courtesy of the Atlantic Terra Cotta Company.
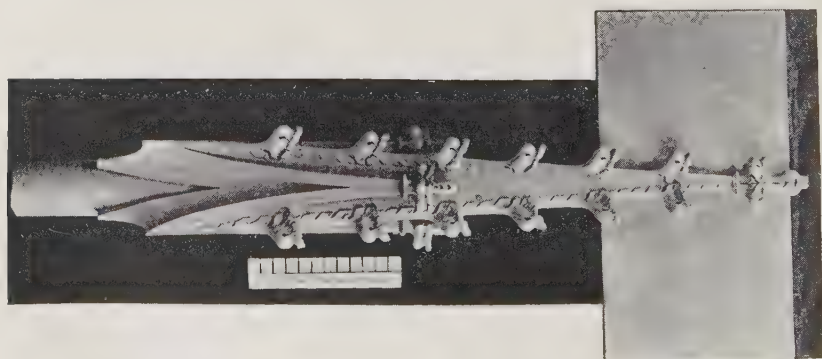
The absorption of this manufactured material, after it is seasoned, compares very favorably with that of the natural stones from which it is manufactured. Only a very small percentage (about 1 per cent) of the weight of the natural stone is lost in crushing and re-assembling into the manufactured article.

This material has been coming very rapidly into use in the East during the last five years. The Onondaga Litholite Company of Syracuse, N. Y., has alone furnished this stone for over four hundred large and prominent structures during the past two years. This material is adapted for use in any place where nat-

Fig. 313.—Plant No. 2 of the Atlantic Terra Cotta Company, Perth Amboy, New Jersey. By courtesy of the Atlantic Terra Cotta Company.

ural stone can be used. It is reasonably low in price and it is particularly adapted for use where a large amount of ornamentation is desired. (See Fig. 306.)

It has this past year been used in a large percentage of the public buildings erected by the State of New York, as well as very extensively for city and municipal work in New York City and throughout the state. It has been used largely in the construction of balustrade and ornamental garden work, as well as bridge construction and in a number of high grade residences constructed in the east. (See Fig. 307.)

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ATLANTIC TERRA COTTA

Atlantic Architectural Terra Cotta is a mixture of various clays covered with a color spray or glaze, and burned in a kiln at a temperature closely approximating 2250 degrees Fahrenheit. the kiln is known as a closed or muffled kiln in which the flames do not come in contact with the material but pass through flues in a double wall.

A covering slip or glaze makes the terra cotta practically impervious and unaffected by weather. Firing in the kiln renders it fireproof.

The economy of terra cotta lies in the methods of manufacture which depend upon the plasticity of the materials used. For plain pieces, such as ashlar blocks and simple modeled courses, a model is made of plaster and from this model a plaster mold is made. The plastic terra cotta body is pressed in this mold and from one mold a great many pieces may be pressed. In a non-plastic material, such as stone, every piece has to be cut or carved separately so that the initial cost is constant for every piece. The economy of modeling and molding as compared to cutting and carving is apparent.

In modeled pieces the model is made of clay and a plastic mold taken from the clay model. It frequently happens in the case of intricate modeling that the work can be executed in terra cotta at one-tenth its cost in natural stone. This saving is particularly great when modeled ornament repeats itself frequently as it does in the pinnacles of the First Baptist Church, Syracuse, N. Y. There are 24,934 pieces of terra cotta in this church. (See Figs. 308, 309, 310, 311, 312 and 313.)

REFERENCES

Baker, Ira O. A Treatise on Masonry Construction; John Wiley and Sons, New York, 1903.

Baker, Ira O. Roads and Pavements; John Wiley and Sons, New York, 1909.

Butler, D. B. Portland Cement; Its Manufacture, Testing and Use. Spon and Chamberlain, London, 1906.

Eckel, E. C. Cements, Limes and Plasters. John Wiley and Sons, New York, 1907.

Eckel, E. C. The Portland Cement Industry from a Financial Standpoint. Moody's Magazine, New York, 1908.

Grant, John. Portland Cement; Its Nature, Tests and Uses. E. and F. N. Spon, London, 1875.

Jameson, C. D. Portland Cement, Its Manufacture and Use. D. Van Nostrand Co., New York, 1898.

Lewis and Chandler. Popular Handbook for Cement and Concrete Users. N. W. Henley Publishing Company, New York, 1911.

Meade, R. K. The Examination of Portland Cement. The Chemcial Publishing Co., Easton, Pa., 1906.

Radford, H. A. Cement and How to Use It. The Radford Architectural Co., Chicago, Ill., 1910.

Reid, H. A. Concrete and Reinforced Concrete Construction. Myron C. Clark Publishinug Co., 1908.

Richards, W. A., and North, H. B. A Manual of Cement Testing. D. Van Nostrand Co., New York, 1912.

Sabin, L. C. Cement and Concrete. McGraw-Hill Publishing Co., New York, 1905.

Spaulding, F. P. Hydraulic Cement, Its Properties, Testing and Use. John Wiley and Sons, New York, 1906.

Taylor and Thompson. A Treatise on Concrete, Plain and Reinforced. John Wiley and Sons, New York, 1904.

APPENDIX I

SOME IMPORTANT STRUCTURES OF THE UNITED STATES

LOCALITY	STRUCTURE.	MATERIAL.
Akron, O.	Memorial Chapel	Sandstone, Marietta, O.
Albany, N. Y.	State Capitol	Granite, Hallowell, Me.
Albany, N. Y.	City Hall	Granite, Milford, Mass.
Allegheny, Pa.	Post Office	Granite, Hallowell, Me.
Ashland, Wis.	Post Office	Sandstone, Houghton, Wis.
Astoria, Ore.	Custom House	Sandstone, near Astoria.
Atlanta, Ga.	Court House and Post Office	Granite, Barre, Vt.
Baltimore, Md.	Court House and Post Office	Granite, Cape Ann, Mass.
Baltimore, Md.	City Hall	Marble, Texas and Cockeysville, Md.
Baltimore, Md.	Peabody Institute	Marble, Texas and Cockeysville, Md.
Bangor, Me.	Custom House and Post Office	Granite, Frankfort, Me.
Boston, Mass.	Custom House	Granite, Quincy, Mass.
Boston, Mass.	U. S. Court House	Granite, Quincy, Mass.
Boston, Mass.	Bunker Hill Monument	Granite, Quincy, Mass.
Boston, Mass.	U. S. Post Office	Granite, Cape Ann, Mass.
Boston, Mass.	Herald Building	Granite, Concord, N. H.
Boston, Mass.	Mass. General Hospital	Granite, Westford, Mass.
Boston, Mass.	Odd Fellows' Memorial Hall	Granite, Hallowell, Me.
Boston, Mass.	Hotel Dartmouth	Marble, Rutland, Vt.
Boston, Mass.	Hotel Vendome (old part)	Marble, Italy.
Boston, Mass.	N. Y. Mut. Life Ins. Bldg.	Marble, Tuckahoe, N. Y.
Boston, Mass.	Young Men's Christian Union	Sandstone, Bay View, New Brunswick.
Boston, Mass.	Harvard College Buildings	Sandstone, Amherst, O.
Boston, Mass.	Central Congregational Church	Conglomerate, Roxbury, Mass.
Boston, Mass.	Chamber of Commerce	Granite, Milford, Mass.
Boston, Mass.	South Union R. R. Station	Granite, Stony Creek, Conn.
Bridgeport, Conn.	Post Office	Sandstone, Middlesex Co., Conn.
Bridgeport, Conn.	Bridgeport Trust Company	Granite, Woodbury, Vt.
Brooklyn, N. Y.	Post Office	Granite, Vinalhaven, Me.
Camden, N. J.	Custom House and Post Office	Marble, Proctor, Vt.
Charlestown, S. C.	Custom House	Marble, Hastings and Tuckahoe, N. Y.
Chicago, Ill.	Court House	Dolomite, Lemont, Ill.
Chicago, Ill.	Chamber of Commerce	Granite, Fox Island and Hallowell, Me.
Chicago, Ill.	Newberry Library	Granite, Stony Creek, Conn.
Chicago, Ill.	Rothschild Building	Granite, Woodbury, Vt.
Chicago, Ill.	Insurance Exchange	Granite, Woodbury, Vt.
Cincinnati, O.	Chamber of Commerce	Granite, Milford, Mass.
Cleveland, O.	City Hall	Granite, Woodbury, Vt.
Columbus, O.	Ohio National Bank	Granite, Woodbury, Vt.
Columbus, O.	Court House and Post Office	Sandstone, Berea, O.
Dayton, O.	Rike-Kumler Building	Granite, Woodbury, Vt.
Dayton, O.	Post Office	Sandstone, Berea, O.
Denver, Col.	State Capitol	Granite, Gunnison, Col.
Des Moines, Ia.	Court House and Post Office	Limestone, Keokuk and Joliet, Ill.
Des Moines, Ia.	City Hall	Granite, Woodbury, Vt.
Detroit, Mich.	Court House and Post Office	Limestone, Bedford, Ind.
Detroit, Mich.	City Hall	Granite, Bethel, Vt.
Evansville, Ind.	Court House and Post Office	Limestone, Bedford, Ind.
Fort Wayne, Ind.	Court House and Post Office	Sandstone, Sand Point, Mich.
Galesburg, Ill.	Burlington Station	Granite, Woodbury, Vt.
Hoboken, N. J.	Stevens Institute Building	Diabase, Jersey City, N. J.
Houghton, Mich.	State Mining School Buildings	Sandstone, Portage Entry, Mich.
Indianapolis, Ind.	Court House	Limestone, Bedford, Ind.
Jacksonville, Fla.	Court House and Post Office	Marble, Georgia.
Jersey City, N. J.	Court House	Diabase, Jersey City, N. J.
Kansas City, Mo.	Court House and Post Office	Granite, South Park, Col., and Llano Co., Texas.
Lansing, Mich.	State Capitol	Sandstone, Amherst, O.
Lidgerwood, N. D.	First National Bank	Granite, Woodbury, Vt.
Little Rock, Ark.	Court House and Post Office	Sandstone, Berea, O.
Lowell, Mass.	Post Office	Granite, Deer Island, Me.
Madison, Wis.	Wisconsin State Capitol	Granite, Bethel, Vt.
Memphis, Tenn.	Union Station	Granite, Woodbury, Vt.

Middletown, Conn. ..Wesleyan University Buildings....Sandstone, Portland, Conn.
Milwaukee, Wis. ....Court House, Custom House, P. O.Granite, Frankfort, Me.
Milwaukee, Wis. ....N'thw't'n. Mut. Life Ins. Co. Bldg.Granite, Woodbury. Vt.
Minneapolis, Minn...Univ. of Min. Buildings......... Dolomitic limestone, Minneapolis, Minn
Mobile, Ala. ....Custom House ....Granite, Quincy, Mass.
Montpelier, Vt. ....State Capitol ....Granite, Barre, Vt.
Montpelier, Vt. ....Post Office ....Marble, Proctor, Vt.
Newark, N. J. ....:Custom House and Post Office....Sandstone, Belleville, N. J.
New Haven, Conn...National Savings Bank...........Granite, Woodbury, Vt.
New Haven, Conn...Osborn Memorial Hall...........Granite, Stony Creek, Conn.
New Orleans, La....Custom House ....Granite, Quincy, Mass.
New York, N. Y....Metropolitan Museum of Art.....Granite, Mt. Desert, Me.
New York, N. Y....New York City Post Office.......Granite, Dix Island, Me.
New York, N. Y....Astor House ....Granite, Quincy, Mass.
New York, N. Y....Obelisk in Central Park...........Hornblende Granite, Egypt.
New York, N. Y....Library of Columbia University...Granite, Stony Creek, Conn., and Milford, Mass.
New York, N. Y....Bankers Trust Co. Building......Granite, Woodbury, Vt.
New York, N. Y....Western Union Tel. Bldg........Granite, Bethel, Vt.
Norfolk, Va. ......Fergus Reid Building............Granite, Woodbury, Vt.
Olean, N. Y. ......First National Bank............Granite, Woodbury, Vt.
Pensacola, Fla. ....Court House and Post Office.....Limestone, Bowling Green, Ky.
Peoria, Ill. ....Court House and Post Office.....Sandstone, Amherst, O.
Philadelphia, Pa. ...Custom House ....Marble, Montgomery Co., Pa.
Philadelphia, Pa. ...Univ. of Pa. Buildings...........Serpentine, Chester Co., Pa.
Pittsburgh, Pa. ....Court House and Post Office......Granite, E. Blue Hill, Me.
Pittsburgh, Pa. ....Pittsburgh Bank ....Granite, Troy, N. H.
Providence, R. I.....City Hall ....Granite, Hurricane Island, Me.; Westerly, R. I., and Concord, N. H.
Providence, R. I.....Turk's Head Building............Granite, Bethel, Vt.
Quincy, Ill. ....Court House and Post Office.....Limestone, Bedford, Ind.
Raleigh, N. C. .....Court House and Post Office.....Granite, Goldsboro, N. C.
Rochester, N. Y. ...Custom House and Post Office....Sandstone, Portland, Conn.
Rochester, N. Y. ...Union Trust Company's Building..Granite, Bethel, Vt.
Rockford, Ill. ......Post Office ....Sandstone, Portage, Mich.
San Jose, Cal. .....Post Office ....Sandstone, San Jose, Cal.
Savannah, Ga. .....Court House and Post Office.....Marble, Pickens Co., Ga.
Scranton, Pa. ......Post Office ....Granite, Hurricane Island, Me.
Sioux Falls, S. D...Court House and Post Office......Quartzite, E. Sioux Falls, S. D.
Springfield, Ill. .....Post Office ....Limestone, Nauvoo, Ill.
Springfield, Mass. ..Post Office ....Sandstone, Long Meadow, Mass.
St. Augustine, Fla...Court House and Post Office.....Coquina, St. Augustine, Fla.
Stanford Univ., Cal..University Buildings ....Sandstone, Santa Clara Co., Cal.
Syracuse, N. Y. ....Fine Arts Buildings S. U.........Sandstone, E. Long Meadow, Mass.
Syracuse, N. Y. ....Hall of Languages S. U.........Limestone, Syracuse, N. Y.
Syracuse, N. Y. ....Jewish Synagogue ....Limestone, Bedford, Ind.
Trenton, N. J. .....State Capitol ....Sandstone, Trenton, N. J.
Trenton, N. J. .....Custom House and Post Office....Sandstone, Amherst, O.
Warren, O. ....Western Reserve Bank...........Granite, Woodbury, Vt.
Washington, D. C...Post Office ....Granite, Vinalhaven, Me.
Washington, D. C...New Post Office ....Granite, Bethel, Vt.
Washington, D. C...New Corcoran Art Gallery.......Marble, Pickens Co., Ga.
Washington, D. C...New Public Library.............Marble, Proctor, Vt.
Washington, D. C...Smithsonian Institution ....Sandstone, Seneca Creek, Md.
Washington, D. C...Union Station ....Granite, Bethel, Vt.
Washington, D. C...Congressional Library Building....Granite, Concord, N. H.
Wichita, Kan. ......Court House and Post Office.....Limestone, Bedford, Ind.
Wilmington, N. C...Court House and Post Office......Sandstone, Sanford, N. C.
Worcester, Mass. ..City Hall ....Granite, Milford, Mass.
Youngstown, O. ....City Hall ....Granite, Woodbury, Vt.
Youngstown, O. ....Mahoning County Court House....Granite, Woodbury, Vt.

APPENDIX II

GLOSSARY

Accessory Mineral.—One not necessary to the definition of a rock but which sometimes determines the variety.

Acid.—A term applied to the igneous rocks containing a high percentage of silica.

Adobe Brick.—A sunbaked brick manufactured from a sandy or calcareous clay and used extensively in warm climates.

Air Brick.—A hollow or pieced brick built into a wall to allow the passage of air.

Air Shrinkage.—The decrease in volume which a clay undergoes when dried in the air.

Alabaster.—A white, massive variety of gypsum. When polished it often resembles some clouded stalagmites.

Alum Shales.—Shales bearing alum formed by the decomposition of pyrite.

Amphibole.—The name for a group of related minerals which are essentially silicates of aluminum, magnesium, calcium and iron, and whose cleavage angles are approximately 56 and 124 degrees.

Andesite.—An eruptive rock whose mineral composition is plagioclase and hornblende or augite.

Anhydrite.—A mineral which in composition is calcium sulphate and which absorbs moisture from the atmosphere when used in base courses as a substitute for marble.

Ankerite.—An objectionable calcium, magnesium and iron carbonate sometimes found in calcareous rocks.

Anorthite.—A calcium feldspar often present in diabase.

Anorthosite.—A granular irruptive rock consisting essentially of labradorite.

Anticline.—The arch part of a folded bed.

Anticlinorium.—A mountain mass arch shaped in its general internal structure.

Apatite.—An accessory mineral sometimes occurring in granites. It is a calcium phosphate.

Aplite.—A fine grained granite consisting of quartz and feldspar. Muscovite may be sparingly present. The outcrop usually occurs as a dike.

Aragonite.—A mineral having the same composition as calcite but crystallizing in the orthorhombic system.

Arch Brick.—A term commonly applied to brick taken from the arches of a kiln. They are usually overburned.

Argillaceous.—A term applied to limestones and sandstones containing clayey matter.

Argillite.—An argillaceous schist or clay slate which breaks readily into thin slabs.

Arkose.—A variety of sandstone containing an appreciable quantity of feldspars.

Asbestos.—A term often applied to fibrous varieties of amphibole or serpentine used in fireproofing.

Ashlar Brick.—A term often applied to brick which have one edge chiseled so as to resemble rock-faced stone.

Augite.—An aluminous pyroxene, the commonest species of the pyroxene group.

Authigenous.—Minerals originating chemically within a rock mass.

Ball Clay.—A white burning clay used as a bond in the manufacture of china ware.

Basalt.—A basic igneous rock consisting of plagioclase and augite. Olivine is a common constituent.

Basic.—A term applied to igneous rocks high in bases and low in their silica content.

Bastard Granite.—A term often applied by quarrymen to granite gneisses.

Bed.—A continuous mass of material deposited under water at about the same time.

Biotite.—A mineral of the mica family. It is essentially a silicate of aluminum, magnesium and iron. It is often called the black mica, the iron mica or the magnesium mica.

Black Coring.—The development of a black core in brick due to improper burning.

Blind Joint.—An obscure bedding plane.

Bluestone.—In New York this term is applied to the bluish gray sandstones. In the District of Columbia it is applied to a mica schist. In Maryland it is applied to a gray gneiss.

Boss.—A dome-like mass of igneous rock, standing above the surrounding country.

Bottom Joint.—A joint or bedding plane in a horizontal or nearly horizontal position.

Boulder Quarry.—A term often applied in Vermont to a granite quarry confined to a group of large boulders. It may be

applied to any granite quarry where the stone is naturally broken up by joints into comparatively small blocks.

Breccia.—A rock made up of angular fragments produced by crushing and then recemented by infiltrating mineral matter.

Brecciated.—A term applied to angular fragments that have not been transported from the place where they were fractured.

Brick Clay.—Any clay that can be used in the manufacture of brick.

Brownstone.—A term formerly applied to the brown sandstones but now somewhat loosely used.

Calcareous.—Containing calcium carbonate.

Calcareous Tufa.—A porous mass of calcium carbonate, deposited on rock ledges, in swamps, on plants and around the mouth of springs.

Calcite.—A mineral consisting of calcium carbonate but crystallizing in the hexagonal system. Its cleavage is rhomohedral, and perfect.

Cellular.—A term often applied to basalts containing cells or cavities.

Chalk.—A soft limestone with earthy texture and normally white color.

Chert.—A cryptocrystalline variety of quartz. The term is often applied to hornstone and to any impure flinty rock.

China Clay.—Any clay suitable for the manufacture of china ware.

Chlorite.—A group name for the greenish colored micaceous minerals. They are silicates of aluminum with magnesium and iron. A secondary mineral derived from the alteration of pyroxene, amphibole, biotite and vesuvianite.

Clastic.—A rock consisting of rock or mineral fragments derived from other rocks.

Clay.—A fine textured unconsolidated rock having a certain amount of plasticity when wet but hardening when burned.

Cleavage.—The natural parting of a mineral due to cohesion. The property of metamorphic rocks to split in certain definite directions.

Clinker Brick.—A very hard burned brick.

Conchoidal Fracture.—A term applied to the break of quartz, certain other minerals and compact rocks whose broken surfaces show concentric rings.

Concretionary.—Made up of rounded aggregations of mineral matter.

Concretion.—A rounded body of mineral matter as chert in

limestone or as calcium carbonate or iron carbonate in certain clays and shales.

Conglomerate.—A rock mass composed chiefly of rounded fragments. Such rocks are sometimes called pudding stone. The term conglomerate often includes the breccias.

Coquina.—A limestone composed of loosely cohering shell fragments cemented together by an infiltration of the carbonate of lime.

Coral Limestone.—Any rock mass composed of the broken fragments of coral.

Cryptocrystalline.—A term applied to the varieties of quartz that are finely crystalline, and to some igneous rocks.

Crystalline Rocks.—A term applied to the metamorphic rocks composed of crystalline mineral grains.

Cutoff.—The direction along which granite must be channeled when it will not split in that direction.

Decomposition.—The breaking down of a rock through the agents of weathering.

Diabase.—A basic igneous rock consisting essentially of plagioclase, augite and magnetite. Olivine may be present. It includes most trap rocks.

Diagonal Joints.—Joints diagonal to the strike of the cleavage in slate.

Diallage.—A thin foliated variety of pyroxene present in many gabbros.

Differentiation.—The process of the separation of a molten solution into portions which form rocks physically or chemically unlike.

Dike.—A long and relatively narrow body of igneous rock filling a fissure at the time it was formed.

Dimension Stone.—Stone quarried and cut of required size.

Diorite.—A basic igneous rock consisting of plagioclase, usually andesine, and hornblende. It is often porphyritic.

Diorite Porphyry.—A basis igneous porphyritic rock of the same mineral composition as diorite.

Dip.—The degree and the direction of the inclination of a bed, cleavage plane, joint, etc.

Disintegration.—A term applied to the mechanical breaking down of a rock on weathering.

Dolerite.—A coarsely crystalline variety of basalt.

Dolomite.—A mineral consisting of the double carbonates of calcium and magnesium. Also a rock made up chiefly of the mineral dolomite.

Down-Draft Kiln.—One in which the heat enters the kiln chamber from the top and passes down through the ware.

Dry.—A seam in a stone, usually invisible in the freshly quarried rock, but which may open up in cutting or on exposure to the atmosphere.

Dryer White.—A white scum which often forms on bricks during the process of drying.

Dry Pan.—A revolving pan used for grinding dry clays. Its bottom is perforated.

Dry-Press Process.—A method of manufacturing clay products from slightly moistened clay by pulverizing and pressing them into steel dies.

Dust Pressed.—Synonymous with dry pressed but usually applied to the manufacture of wall tile.

Enameled Brick.—Brick which are coated on one or more surfaces with a white or colored enamel.

Encaustic Tile.—A term applied to floor tile which has a surface pattern of one type of clay and a backing of a different type.

End Joint.—A vertical joint about parallel to the direction of the cleavage dip.

Epidote.—A peculiar yellowish-green mineral sometimes occurring in granites. In composition it is a silicate of calcium, aluminum and iron.

Erosion.—The wearing away of a rock surface by mechanical and chemical agencies.

Essential Minerals.—Those necessary to the definition of a rock.

Eruptive.—Igneous rocks that have been extruded.

Extrusive.—Igneous rocks which have cooled after reaching the surface.

False Cleavage.—A secondary slip cleavage superinduced on slaty cleavage.

Fault.—A dislocation caused by a slipping of rock masses along some plane of fracture. Also the dislocated structure resulting from such slipping.

Feldspar.—A name applied to a group of minerals possessing several characteristics in common. They are silicates of aluminum with potassium, or sodium, or both, or with calcium, or sodium and calcium. Iron and manganese are absent. Their cleavage is perfect.

Felsite.—A cryptocrystalline mixture of quartz and feldspar. The ground mass of the quartz porphyries.

Felspathoid.—A group of minerals that may replace the feld-

spars in the formation of igneous rocks. Leucite, nephelite and sodalite are the most common.

Femic.—A term applied to rocks rich in iron and magnesium.

Ferruginous.—Containing either the anhydrous or hydrous oxides of iron.

Ferromagnesian.—A term applied to the dark colored silicates which contain both iron and magnesium.

Fire Clay.—A very refractory clay used in the manufacture of fire brick and crucibles.

Fireproofing.—A name applied to products used in floor arches, partitions, etc., to render a building fireproof.

Fire Shrinkage.—The decrease in volume which a clay undergoes during the process of burning.

Fissility.—The tendency shown in slate to separate into thin laminae.

Flagstone.—A term applied to sandstones which split readily into blocks suitable for flagging purposes.

Flashed Brick.—A term applied to brick whose edges have been darkened or rendered spotted by special treatment in their manufacture.

Flint.—A cryptocrystalline variety of quartz, breaking with a deep conchoidal fracture and a sharp cutting edge. Also a term applied to quartz veins and beds of quartzite in slate.

Flue Linings.—Cylindrical or rectangular pipes used for lining flues.

Flow Structure.—A banding produced in many igneous rocks by a flowage of the mass while soft.

Fluorite.—A mineral consisting of calcium fluoride.

Foliation.—The arrangement of the minerals in a crystalline rock in parallel layers.

Forest Marble.—An argillaceous limestone in which the coloring matter is so distributed as to resemble landscapes.

Formation.—A mapable area of beds possessing common and general characteristics.

Fossiliferous.—Containing any record of an organism preserved in the crust of the earth.

Freestone.—A term applied to any stone that will work easily and freely in any direction.

Furring Brick.—Hollow brick used for lining the inside of a wall.

Gabbro.—A basic igneous rock consisting of plagioclase, usually labradorite, and a pyroxene, usually augite or diallage. Magnetite is often present and some varieties bear olivine.

Garnet.—A silicate of aluminum, calcium, iron or magnesium,

which crystallizes in the isometric system. The common garnet in metamorphic limestones is grossularite. The one in mica schists is almandine.

Gneiss.—A metamorphosed igneous rock having its ferromagnesian minerals arranged in more or less massive bands or layers. Also a metamorphosed highly feldspathic sedimentary rock.

Gneissoid Granite.—Having a structure somewhat resembling a gneiss.

Grain.—An obscure vertical cleavage more or less parallel to the end or dip joints.

Granite Porphyry.—An igneous rock with the same mineral composition as granite, but with a porphyritic texture.

Granitoid.—Having a texture like that of granite.

Granodiorite.—A diorite bearing an appreciable amount of quartz.

Graphite.—A soft metallic, dark steel gray mineral consisting of carbon.

Gravel.—Small stones or fragments of stones.

Graywacke.—A compact sandstone consisting of quartz, feldspars and argillaceous matter.

Greenstone.—An indefinite term often applied to the basic igneous rocks of greenish color due to the presence of chlorite.

Grit.—A term applied to sandstones when suitable for whetstones.

Grog.—Pulverized burned clay or brick which is often added to the raw clay mixture to decrease the shrinkage and density of the burned ware.

Gumbo.—A term applied to the soils which yield a sticky mud when wet. This is characteristic of the mud of the prairies.

Gypsum.—A hydrous calcium sulphate which is 2 in the scale of hardness.

Hardness.—The power of a mineral to resist abrasion. The scale of hardness varies from 1 to 10.

Hardpan.—A layer of hard detritus under soft soil.

Hardway.—A direction of splitting at right angles to the rift and grain.

HCl.—Hydrochloric or muriatic acid.

Header.—A brick or stone laid with its longer axis at right angles to the surface of the wall.

Heading.—A term often applied by quarrymen to a group of close joints.

Hematite.—An anhyrous oxide of iron whose fine powder is of cherry red or blood red color.

Hip.—A piece of roofing tile required where a hip starts from a ridge.

Hip-Roll.—A tile used for covering the hips on roofs.

Hip-Tile.—Tile which run up against a hip stringer.

HNO₃.—Nitric acid.

Hogback.—Shear zones.

Hollow Blocks.—These are usually rectangular in form and hollow. They are used in exterior walls and partitions.

Hollow Brick.—Brick molded with hollow spaces in them, and strengthened by cross webs.

Holocrystalline.—A term applied to rocks wholly composed of crystalline constituents.

Hygroscopic.—The ability of a rock or chemical compound to absorb or condense moisture from the atmosphere.

Hypersthene.—A mineral of the pyroxene group present in norite.

Iceland Spar.—A popular name for transparent calcite used for polarizing light.

Igneous Rocks.—Rocks formed by the action of heat with sufficient intensity to effect fusion.

Inclusions.—Fragments of one kind of rock inclosed in another type of rock.

Interlocking tile.—Roofing tile with edges and grooves which interlock when the tile are laid on the roof.

Irruptive.—A term used to denote the igneous rocks that have worked their way upward from the zone of flowage through other rocks but have not flowed out over the surface.

Isoclinal.—A fold with sides nearly parallel.

Itacolumyte.—A friable and flexible sandstone, especially when in thin slabs. Its flexibility is due to the interlocking of the quartz grains.

Jasper.—A cryptocrystalline variety of quartz, usually red or brown in color. A term applied also to the marbles of Vermont which in color closely resemble the mineral jasper.

Joints.—Fractures which may occur in any kind of rock. In position they vary from horizontal to vertical. When horizontal in granite they develop a sheeted structure.

Kaolin.—A white residual clay assuming rock proportions and used in the manufacture of wall tile, china ware and sanitary ware.

Kaolinite.—A mineral which is a hydrous silicate of aluminum resulting from the decomposition of feldspars.

Kiln White.—A scum which often appears in the burning of brick.

Knots.—A term applied to the concretions sometimes found in granites and gneisses. Also to the concretions present in sedimentary rocks.

Labradorite.—A mineral of the feldspar group, usually gray in color, crystallizing in the triclinic system, and with cleavage planes finely striated.

Lava.—Molten material poured out from a volcano. Molten rock intruded subterraneously between strata. It is applied also to the same material after it has cooled.

Ledge.—A term applied to a single bed or to a group of beds occurring in a quarry. Also to any outcrop of rock on the surface.

Lift.—A name often applied by quarrymen to joint planes which are approximately in horizontal position.

Limestone.—A rock mass consisting of calcium carbonate, which through metamorphism passes into a marble.

Limonite.—A brown or yellow mineral which chemically is a hydrous oxide of iron, $2Fe_2O_3, 3H_2O$.

Liparite.—A lava rich in silica, especially abundant in the Lipari Islands.

Loess.—A pale, yellowish, homogeneous, calcareous clay, loam or sand of Pleistocene age.

Luster.—The quality and quantity of light reflected by a mineral.

Magma.—The molten material from which the igneous rocks are formed.

Magnesite.—A white to brown magnesium carbonate crystallizing in the hexagonal system. It is often found massive.

Magnetite.—A black iron oxide which is strongly magnetic both before and after heating. It crystallizes in regular octahedrons.

Mantle-Rock.—The loose fragmental material that results from the disintegration of both igneous and sedimentary rocks.

Marble.—A metamorphosed limestone or dolomite. A massive variety of calcite which is capable of being polished and used for architectural and ornamental purposes.

Marcasite.—A white iron pyrite which crystallizes in the orthorhombic system. It is more readily decomposed than the other sulphides of iron.

Matrix.—A term used for the unindividualized material in igneous rocks. Also the chief substance of a slate itself.

Matt Glaze.—A dull glaze applied to some clay products.

Melaphyre.—A term applied to any igneous porphyry with a dark ground mass.

Metamorphism.—The process by which a rock is altered in the molecular structure of its minerals and in their arrangement.

Mexican Tile.—A term applied to roofing tile with semicircular cross section.

Mica.—The name of a group of minerals with eminent basal cleavage. They are essentially hydrous silicates of aluminum with potassium, magnesium and iron. Sodium and lithium micas are well known.

Micaceous Sandstone.—One containing many scales of mica.

Microcline.—A potassium, aluminum silicate of the feldspar group, crystallizing in the triclinic system. It frequently occurs in granite.

Mineral.—A natural inorganic element or compound with theoretically a definite chemical composition, and usually a definite crystalline form.

Molded Brick.—A term often applied to soft-mud brick.

Monocline.—An abrupt downward folding of nearly horizontal strata, without any corresponding bend to form an anticline or syncline.

Monzonite.—A rock which is intermediate in mineral composition between a syenite and a diorite.

Muscovite.—The common potassium member of the mica group. It is often called the white mica. Also the potassium mica.

Nephelite.—A silicate of aluminum, sodium and potassium which crystallizes in the hexagonal system and occurs as small crystals or grains in the intermediate igneous rocks. The variety eleolite is distinguished by its greasy luster.

Norman Tile.—A brick with dimensions of 12 by $2\frac{1}{4}$ to $2\frac{1}{2}$ inches.

Novaculite.—An exceedingly fine grained sandstone, abundant in Arkansas, and used for hones and whetstones.

Obsidian.—A common name for volcanic glass.

Oligoclase.—A white, sodium, calcium and aluminum silicate of the feldspar group. It is a common plagioclase mineral in granites.

Olivine.—An olive green silicate of magnesium and iron crystallizing in the orthorhombic system. It occurs in the basic and ultra-basic igneous rocks.

Onyx.—The true onyx is a cryptocrystalline variety of quartz which closely resembles an agate. The onyx marble is a compact variety of limestone which is noted for its translucency, and often a delicate arrangement of colors more or less banded.

Oolite.—A granular limestone made up of concentric coats of

the carbonate of calcium deposited around minute nuclei. The grains are about the size of the roe of a fish.

Opal.—A noncrystalline hydrous variety of quartz.

Ophicalcite.—A term often applied to the coarsely crystalline marbles containing serpentine.

Ophimagnesite.—A rock consisting of crystallized magnesite and disseminated serpentine.

Ophitic.—Consisting of interlacing lath-shaped crystals of feldspars whose interspaces are chiefly filled with pyroxenes of later growth.

Orbicular.—An igneous rock having its component minerals crystallized or segregated in spheroidal forms. The term is applied to the granite of Craftsbury, Vermont, and to the diorite of San Diego, California.

Ornamental Brick.—A term often applied to front brick which have the surface ornamented with some form of design.

Orthoclase.—The potassium aluminum silicate of the feldspar group, which crystallizes in the monoclinic system. It is a necessary mineral constituent of all granites.

Pale Brick.—A brick which is underburned.

Paving Brick.—Vitrified blocks which are used for paving purposes.

Pegmatite.—A very coarse grained phase of the granite rocks which usually occurs in dikes or lenses intruded in granites and metamorphic rocks.

Peridotite.—An ultra-basic igneous rock consisting essentially of olivine.

Phenocryst.—One of the prominent crystals in a rock of porphyritic texture.

Phlogopite.—An amber mica which often occurs in marbles and serpentines.

Pholerite.—A hydrous silicate of aluminum derived from the decomposition of orthoclase.

Phonolite.—A felsitic lava which rings when struck with a hammer.

Phyllite.—A fine grained metamorphic rock intermediate between a slate and schist.

Pipe Clay.—A term applied to clays used for the manufacture of sewer pipe.

Pisolite.—A concretionary limestone with the globules about the size of small peas.

Pitch.—The inclination of the axis of the fold of a rock.

Plagioclase.—A collective name for the triclinic feldspars other than microcline.

Plasticity.—The property of certain clays to form a plastic mass when mixed with water.

Plutonic.—A term applied to the granitoid igneous rocks which have cooled a considerable distance below the surface of the earth.

Porphyritic.—A term applied to those igneous rocks which contain phenocrysts of some mineral in a finer grained ground mass.

Pozzuolana.—A volcanic ash used as an hydraulic cement.

Pressed Brick.—A term applied to smooth-faced front brick.

Pseudomorph.—A mineral that has assumed the crystal form of a different mineral as a result of the partial or entire alteration or replacement of the original mineral through chemical processes.

Pudding Stone.—Conglomerate rock containing numerous rounded pebbles.

Pugging.—The tempering of wet clay.

Pug Mill.—A machine for tempering or mixing wet clay.

Pyrite.—A common, yellow, metallic sulphide of iron which crystallizes in the isometric system.

Pyroxene.—A group of bisilicate minerals whose cleavage angles are approximately $87\frac{1}{2}$ degrees and $92\frac{1}{2}$ degrees. Augite is the most important member of the group.

Pyroxenite.—A basic igneous rock consisting essentially of pyroxenes.

Quarry.—An opening made in an outcrop of rock with the purpose of obtaining stone for commercial purposes.

Quarry Water.—The water present in the interstices of a stone when it is quarried.

Quartz.—A form of silica occurring in hexagonal crystals or in cryptocrystalline massive forms.

Quartzite.—A metamorphic sandstone whose cement is silica.

Quartz Monzonite.—An igneous rock of granitic texture containing quartz with the plagioclase minerals equal or in excess of the orthoclase.

Quartz Porphyry.—An igneous porphyritic rock of the same mineral composition as granite but with quartz occuring as phenocrysts.

Repressed Brick.—Brick which after being molded are run through a second pressing machine to improve their form.

Residual Clay.—One formed by the decay of rocks in situ.

Rhyolite.—An igneous rock with the same mineral composition as granite but usually with a porphyritic texture.

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Rhodonite.—A silicate of manganese which is susceptible of a high polish and is suitable for decorative interior work.

Ribbon.—A line of bedding or a thin bed appearing on the cleavage surface in slate. Sometimes it is of a different color from the slate.

Ridge Tile.—A roofing tile used at the roof ridge.

Rift.—A microscopic cleavage in building stones which greatly aids in the process of quarrying.

Ring Pit.—A circular pit in which clays are tempered by use of a large revolving wheel.

Rock-Face Brick.—Brick with their surface chiseled so as to resemble cut stone.

Roman Tile.—Either dry pressed or stiff-mud repressed brick of dimensions 12 by 4 by $1\frac{1}{2}$ inches.

Roofing Tile.—A term applied to a burned clay tile used for roofing purposes.

Run.—A term used to denote the course of the rift.

Saccharoidal.—A texture resembling that of loaf sugar.

Salmon Brick.—Underburned brick which are of a pale salmon color.

Salt Glaze.—A glaze produced on sewer pipe and stoneware by adding salt to the kiln fires during the process of burning.

Sand.—Finely comminuted fragments and water worn particles of rocks.

Sandstone.—A sedimentary rock consisting of grains of sand held together by some cementing material.

Sap.—A term often used by quarrymen to denote the more or less weathered portion of any rock mass.

Saprolite.—Thoroughly decomposed but untransported rock.

Schist.—A metamorphic rock which has a parallel or foliated structure secondarily developed by shearing. Schists frequently consist of grains of quartz and scales of mica arranged in more or less parallel layers. Feldspathic particles may be present.

Schistose.—Having the structure of a schist.

Scove Kiln.—A temporary kiln often used in burning common brick.

Sculping.—Fracturing the slate along the grain; that is, across the cleavage in the direction of the dip.

Seam.—A term often used for any fracture occurring in a rock mass.

Sedimentary Rocks.—Those which have been deposited after being more or less sorted by running water.

Selenite.—A variety of gypsum which is transparent and usually occurs in plates.

Semi-Dry-Press Process.—Closely related to the dry-press process but the clay is more moist.

Sericite.—An altered muscovite occurring in scales or fibrous forms.

Serpentine.—A metamorphic rock consisting essentially of the mineral, serpentine. The coarser massive varieties are used as structural stone. The more highly colored varieties for interior decoration.

Settle.—The amount of fire shrinkage which takes place in a kiln of brick during the process of burning.

Sewer Brick.—Low absorption brick used as sewer linings.

Shale.—A fine grained, laminated, argillaceous rock, usually with friable structure.

Shaly.—A term used to describe a thin bedded rock which breaks up like shale.

Sheeted Structure.—A term applied to those granite quarries which have well defined horizontal joints and but few vertical joints.

Shingle Tile.—A flat form of roofing tile.

Shrinkage.—The decrease in volume which clays undergo during the processes of drying and burning.

Siderite.—A carbonate of iron which crystallizes in the hexagonal system in rhombohedrons with curved faces. When present in a building stone it is an objectionable accessory constituent.

Siding Tile.—Any roofing tile used in upright work.

Siliceous.—Containing an appreciable amount of silica as an impurity.

Silt.—A muddy deposit in bays and harbors. A soil whose grains vary from .05 to .005 mm. in size.

Slate.—A metamorphosed clay or shale. It usually has a well developed cleavage which is at right angles to the pressure which aided in the metamorphism.

Slickensides.—Polished and grooved surfaces produced by one mass of rock sliding over another as along a fault plane.

Slip.—Joints crossing the cleavage but of no great continuity.

Slip Clay.—Any easily fusible clay.

Slip Cleavage.—Microscopic folding and fracture which is accompanied with slippage.

Slip Glaze.—One produced by the use of slip clay.

Slop Brick.—A term often applied to soft-mud brick.

Slurry.—A term applied to the semi-wet mixture when ground and ready for burning in rotary kiln.

Soak Pit.—A pit in which clay is soaked before molding.

Soft-Mud Process.—A method of molding brick by forcing them into wooden molds.

Spanish Tile.—A term applied to roofing tile with an S-shaped cross section.

Specific Gravity.—The weight of a mineral or rock when compared with the weight of an equal volume of water.

Split.—A slaty cleavage.

Stalactite.—An icicle-like deposit of the carbonate of calcium, formed on the roof of caves by the evaporation of the solvent.

Stalagmite.—A deposite of the carbonate of calcium formed on the floor of caves by the evaporation of the solvent.

Steatite.—A massive variety of talc.

Stiff-Mud Process.—A method of molding brick by forcing plastic clay through a die.

Stock.—A large columnar mass of igneous rock with appoximately equal length and breadth.

Stock Brick.—The carefully selected bricks of a kiln.

Stratification.—Bedding, in distinction from cleavage.

Stratum.—A layer or bed of rock.

Stretcher.—A stone or brick laid with its longer axis parallel to the face of the wall.

Strike.—A direction at right angles to the inclination of a plane of bedding, cleavage, or jointing ; the trend of an outcrop.

Strike Joint.—A joint parallel to the strike of the cleavage.

Stripping.—The process of removing worthless material from a quarry.

Sulphur.—A term often used by quarrymen to denote iron pyrite. Also the element sulphur.

Syenite.—An intermediate igneous rock whose mineral composition is essentially orthoclase and hornblende.

Syenite Gneiss.—A sheared syenite. A syenite with its ferro-magnesian minerals arranged in parallel layers.

Syenite Porphyry.—A rock with porphyritic texture but of the same mineral composition as a syenite.

Syncline.—The trough part of a fold of rock.

Synclinorium.—A mountain mass with its general internal structure trough-shaped.

Talc.—A hydrous silicate of magnesium which is number 1 in the scale of hardness.

Talc Schist.—A schistose rock consisting essentially of talc and quartz.

Talus.—The collection of earth and broken rock at the foot of a cliff or steep slope. This material when angular is sometimes cemented together as a talus breccia.

Tapestry Brick.—Brick made by the stiff-mud process and having all surfaces roughened by wire cutting.

Tempering.—The process of properly mixing clays before molding.

Terra Cotta.—A kind of hard pottery used for statues and architectural decorations. Sometimes applied to a certain type of blocks used in constructional work.

Terra-Cotta Clay.—Any clay that may be used in the manufacture of terra cotta.

Terra-Cotta Lumber.—A term applied to fireproofing shapes of clay ware which are soft and porous.

Thick Joint.—Two or more parallel joints between rocks which have been broken up or decomposed.

Till.—A mixture of clay and pebbles which have been left by a glacier.

Toe Nail.—Curved joints intersecting a sheet structure.

Top.—The weathered portion or shattered upper portion of any rock mass.

Trachyte.—An intermediate eruptive rock consisting essentially of orthoclase and one or more ferromagnesian minerals.

Trap.—A field name for any dark fine grained igneous rock.

Travertine.—A calcareous rock deposited from solution. The compact, translucent variety is known as onyx marble.

Tremolite.—A white variety of amphibole which sometimes occurs as an objectionable constituent in marbles.

Unakite.—A peculiar granite whose mineral composition is orthoclase, quartz and epidote.

Unctuous.—Having a greasy or soapy feel.

Updraft Kiln.—A kiln in which the heat enters from the bottom and passes upward through the ware during the process of burning.

Valley Tile.—Roofing tile made to fit the valley of a roof.

Vein.—A more or less regular mineral mass consisting of quartz, with or without calcite. Its presence is objectionable in a slate quarry. Also the filling of a fissure.

Verd Antique.—A metamorphic rock consisting essentially of serpentine traversed by veinlets of talc, calcite or dolomite. It is susceptible of a polish, and is a marble only in a commercial sense.

Vesicular.—A term often applied to lavas containing air or gas cavities.

Volcanic.—A term applied to surface flows of igneous rocks to distinguish them from rocks which have cooled from molten solution beneath the surface.

Volcanic Ash.—A term applied to the fine grained volcanic ejectamenta. When consolidated it is sometimes used for building purposes.

Volcanic Tuff.—A consolidated volcanic ash.

Wall White.—A white scum often seen on brick after setting in a wall.

Waves.—A term often applied to annelid trails.

Weathering.—A term applied to the changes that occur in rocks due to physical and chemical agencies.

Whitewash.—A term applied to the white scum of soluble sulphates which often appears on the surface of brick and other clay products either during or after their manufacture.

Wind Rock.—A term applied to slate unfit for commercial purposes.

Xenolith.—A mass of rock included in any irruptive in its migration towards the surface.

Zeolites.—A name for a group of closely related minerals which are essentially hydrous silicates of aluminum, with potassium, sodium, calcium and more rarely barium. They are of secondary origin.

Zircon.—A silicate of zirconium, which crystallizes in the tetragonal system and often occurs as an accessory mineral in granite.

Zonation.—The arrangement of igneous rocks in more or less concentric belts or zones due to differentiation during the process of cooling. It is the most pronounced near the walls where cooling began.

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